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The Effect of Fixed Wing Slots on the Stall Characteristics of a Modern Bi-Motor Airplane

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ABSTRACT

A major problem facing the designers of present-day aircraft is to combine desirable flying qualities with high performance. Blind flying has placed particularly stringent requirements upon low speed maneuverability and stability, as well as upon desirable stall characteristics.

Extensive flight testing of a typical modern transport revealed that the stall was preceded by insufficient warning for the pilot and occurred with a high rate of roll, particularly for the power-on stalls. Fixed wing slots were incorporated in the basic model and produced gratifying results. Quantitative measurements of the stall were made using specially designed equipment described also in this paper.

THE stall characteristics of the present modern airplane leave a great deal to be desired. In an effort to obtain high aerodynamic and structural efficiency, it was the general practice for airplane designers a few years ago to use high taper ratios, little or no aerodynamic twist, and airfoil sections which gave very sharp flow separation at the stall. It has been well known that increasing the taper causes an induced up-wash at the wing tips which causes premature stalling at this section of the wing unless special precautions are taken to avoid tip stall. Fig. 1 shows the tendency of taper ratio to increase premature stalling at the wing tip as the taper ratio is increased from 2.5 to infinity. The effective angle of attack at the tip sections varies from 13 percent to about 70 percent above that of the wing center section as the taper ratio increases.

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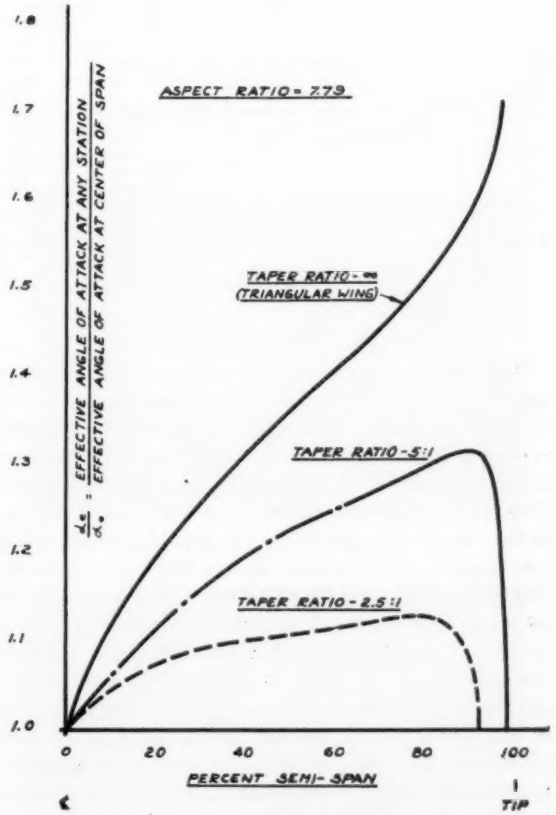


FIG. 1. Effect of taper on stalling characteristics. Zero wing twist—constant aspect ratio.

The desirability of high taper ratio is quite apparent when the various structural factors are considered. This is particularly true when high wing loading and aspect ratio are desired, or where it is necessary to install large fuel tanks, or the landing gear in the wing and to improve the aileron control below the stalling angles.

Fig. 2 shows the characteristics of the basic wing of the Lockheed Model 14 airplane on which a great deal of research has been done on the study of wing stalling phenomena.

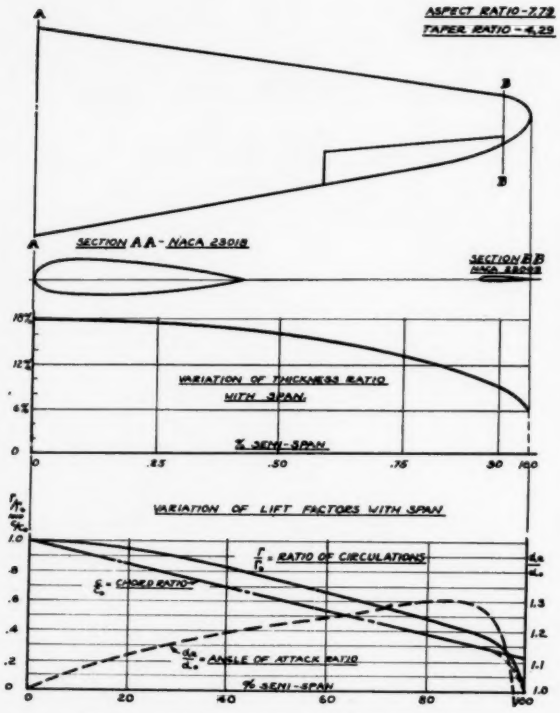


FIG. 2. Basic wing data, Lockheed Model 14.

SLIPSTREAM EFFECT

On modern multi-engined airplanes, the propeller slipstream effect can change the wing stalling characteristics substantially. Naturally, the greater the amount of power, or the higher the percentage of the wing area in the slipstream, the greater the effect from this source. Bi-motored airplanes may have as much as 50 percent of the wing area affected by the propeller wash, while four-engined airplanes may have as much as 75 percent. The effect of the propeller slipstream is generally greatest with the wing flaps extended, inasmuch as the increase in circulation caused by the higher flow velocity induces a greater up-wash at the wing tips and tends to aggravate tip stalling conditions. The slipstream effect is very beneficial on take-off, giving increase in wing lift of from 25 to 40 percent. The slipstream factor becomes more important on stall characteristics as wing loadings increase and flaps come into more common use for take-off. The tendency of the propeller wash to eliminate the fuselage wing intersection burbling which normally tells the pilot of the impending stall, has taken from the pilot a warning he normally needs for safe flying. The most dangerous time the pilot can stall the airplane is on take-off, as the airplane is liable to be thrown into the air from a rough field or by gust which can precipitate a stall. This condition is being given a great deal of attention in the design of new aircraft of all types.

THE CASE OF THE LOCKHEED 14

The Lockheed Aircraft Corporation was faced with the problem of wing stalling characteristics with its Model 14 airplane. When this airplane was developed, the latest N.A.C.A. airfoil sections were used along with a taper ratio of 4.29:1 and a large Fowler flap incorporated as a high lift device. Subsequent flight tests of the airplane showed it to have very sudden tip stalling characteristics for the power-on condition, particularly for the take-off power condition. This was accompanied by no warning, although it occurred at a very high angle of attack and at a low airspeed. For the rearward center of gravity position, the stick forces and stick positions for stalling differed very slightly from those normally required for cruising and climbing. It was necessary to develop a take-off technique based upon the pilot's observation of the airspeed indicator in order to insure his having an ample margin of speed above the stall. In an effort to solve the problem encountered, the Lockheed Aircraft Corporation instigated an investigation covering a period of a year, during which time the stall characteristics of the original wing were carefully studied, both in flight and in the wind tunnel. Efforts were made to develop an angle of attack indicator for pilot warning, three different wing modifications of the tip were tried, and finally, a thorough investigation was made which resulted in the development of the fixed wing slot now in current use on the airplane. In the course of the flight tests, several hundred complete stalls were made under all conceivable conditions of flap setting, power, and loading.

FLIGHT TESTS WITH ORIGINAL WING

The first step in the stall investigation was to develop methods of measuring quantitatively the control positions, rate of roll, yaw, and pitch of the airplane in the stalls, the altitude lost or gained, the tendency to spin, and other factors of this nature. The equipment used consisted of one movie camera taking pictures of woolen tufts attached to the upper surface of the wing, a trailing static bomb and swiveling pitot head for airspeed measurement, and a supplementary instrument board which was photographed by a second movie camera. This special instrument panel was built to accommodate fourteen instruments and was mounted on one end of a tapered wooden box on the other end of which was mounted a 16 mm. movie camera. The distance from the instrument panel to the lens of the camera was 6

feet. Special reflectors were designed to house an airplane landing light of 575,000 beam candles on each side of the instrument panel. These reflectors were designed to provide as uniform lighting as possible without direct reflection into the camera. It was found that the outer edge instruments would reflect light into the camera, but these reflections were eliminated by tilting the instruments toward the center.

The instruments that were photographed on the special panel were as follows:

(1) Air Temperature Gage—Capillary Type.
(2) Sensitive Altimeter.
(3) Airspeed Indicator—Airplane Pitot Tube.
(4) Airspeed Indicator—Trailing Static Bomb.
(5) Accelerometer.
(6) Clock.
(7) Turn and Bank.
(8) Gyro-Horizon.
(9) Sperry Directional Gyro.
(10) Left Aileron Angle Indicator.
(11) Right Aileron Angle Indicator.
(12) Elevator Angle Indicator.
(13) Rudder Angle Indicator.
(14) Angle of Attack Indicator.

The control surface angle instruments consisted of General Electric DC Selsyn transmitters and indicators which were attached directly to the control surfaces to eliminate the effect of cable stretch.

In making the various stalls, an attempt was made to pull up with the same rate of change of angle in each case. The rate chosen was that which seemed to be typical of an inadvertent stall of this particular airplane which was roughly a rate of change of speed of 30 miles per hour per minute.

Figs. 3 to 6 show the equipment used in the stall tests.

Figs. 7 and 8 show the wing with flaps retracted in the unstalled and stalled condition. It will be noted that an airspeed indicator and a clock are mounted on one flap track fairing to give a correlation of time and speed between the tuft pictures and the instruments in the recording box.

Fig. 9 is a similar flow picture showing the stalled wing with the flaps extended.

Fig. 10 shows a photograph of the special instrument panel after the airplane has fallen off in a complete stall. It is interesting to note the airspeed reading, the angle of turn and bank, and the various control positions.

Figs. 11, 12, 13, and 14 show typical examples of the data obtained in typical stalls with various flap settings and power conditions. The accuracy of the readings obtained is excellent. The sharpness of the stall is particularly noticeable in reading the angle of bank against time. It will be noted that rates of roll as high as 40° per second were obtained. The true indicated speed noted is that obtained from the trailing static bomb which was suspended approximately 60 feet away from the airplane, and the swiveling pitot head located on the nose of the airplane (see Fig. 3). The ship indicated speed is the reading obtained on the airplane airspeed indicator connected to the normal pitot-static tube of the aircraft. From the data obtained by the two movie cameras, the stall contours (Figs. 15 and 16) are plotted, indicating the lines of flow separation for various conditions of power and flap setting. Due to camera limitations, only the section of the wing outboard of the engine nacelles can be shown. The tendency toward tip stalling is very apparent and a careful study of the movies indicate that the rate of stall progression is as high as 32 feet per second. It is

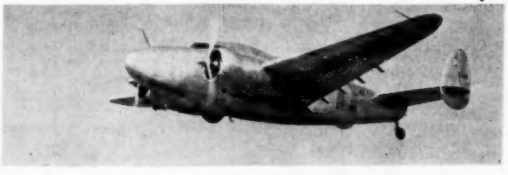


FIG. 3. Lockheed Model 14 in flight.

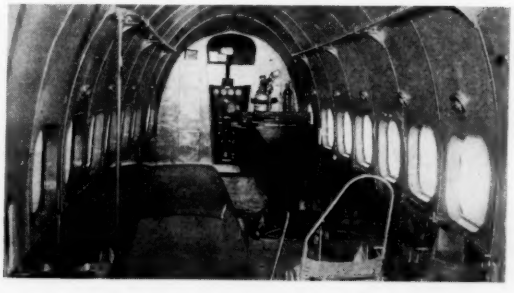


FIG. 4. Installation of test equipment.

FIG. 5. Lowering the airspeed bomb.

FIG. 6. Taking movies of the wing during a stall.

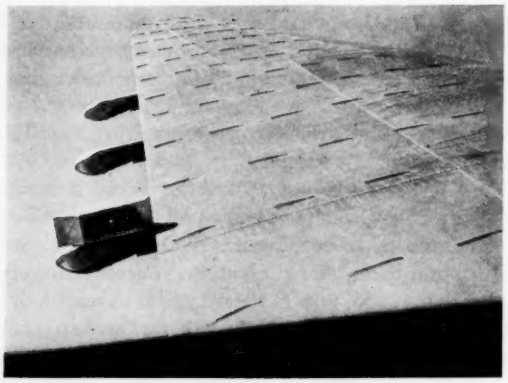


FIG. 7. Unstalled wing—flaps up.

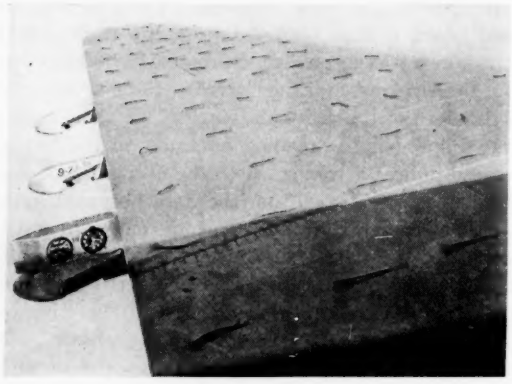


FIG. 8. Stalled wing—flaps up.

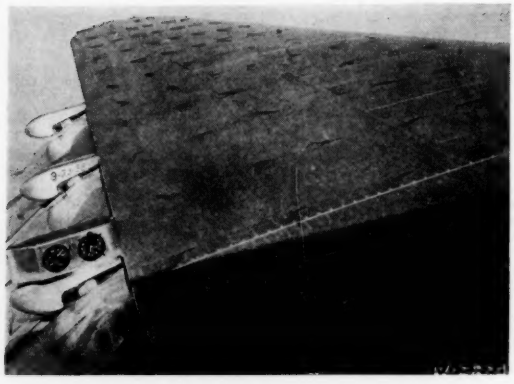


FIG. 9. Stalled wing—flaps down.

this factor which gives rise to the high rate of roll. With the original wing, it may be seen that the stall has a tendency to start near the center of the wing span for the power-off, flap-up condition, but it starts definitely at the tip for the power-on condition. The lift coefficients obtained with the power-off condition and the apparent lift coefficient obtained with approximately 570 hp. per engine as shown in Fig. 18.

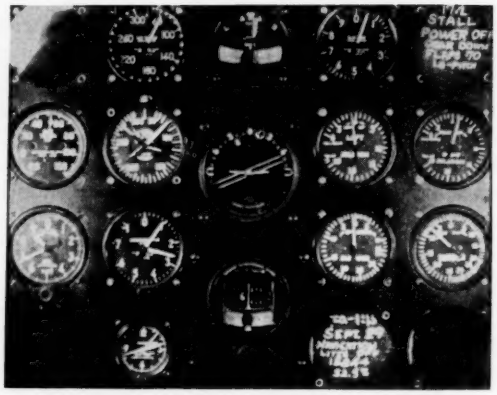


FIG. 10. Instruments during a stall.

ANGLE OF ATTACK INDICATOR

During original stalling tests, development work was carried on in an effort to develop an angle of attack indicator which would continuously record the true angle of airflow to the wing and which could give the pilot warning under all condititions of his approach to the stall. This unit consists of a small elliptical shaped low aspect ratio airfoil located alongside the airplane pitot-static tube. It has one pressure orifice near its leading

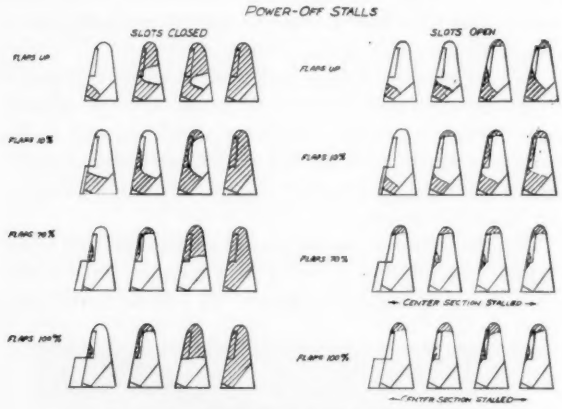


FIG. 15. Stall contours with power off.

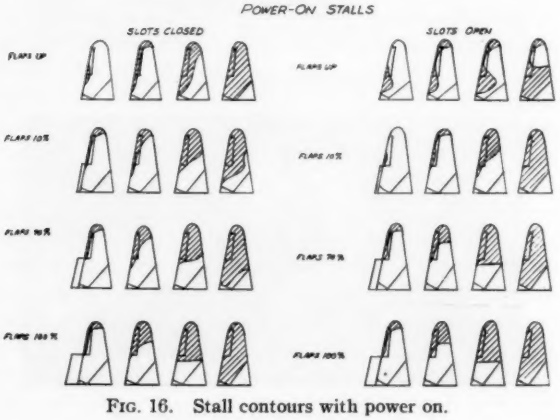


FIG. 16. Stall contours with power on.

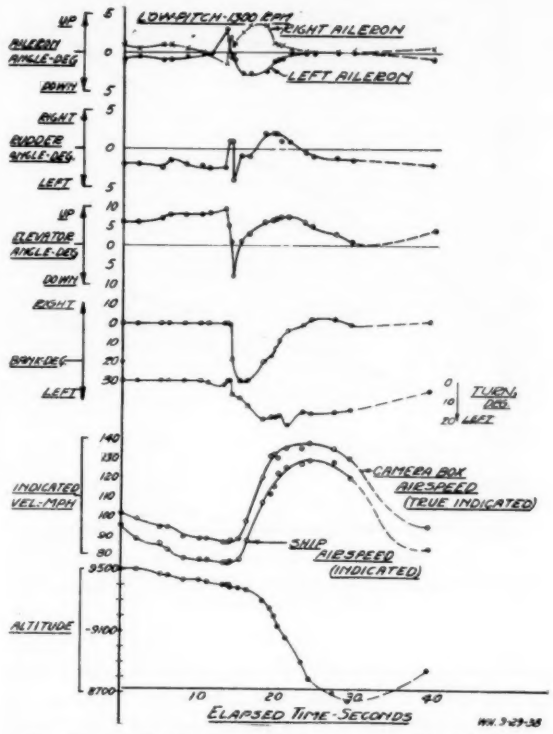


FIG. 11. Stall with power off, flaps up. Stall test No. 14.1; gross weight, 15,584 lbs; c.g., 31.8 percent; low pitch, 1300 r.p.m.; landing gear down.

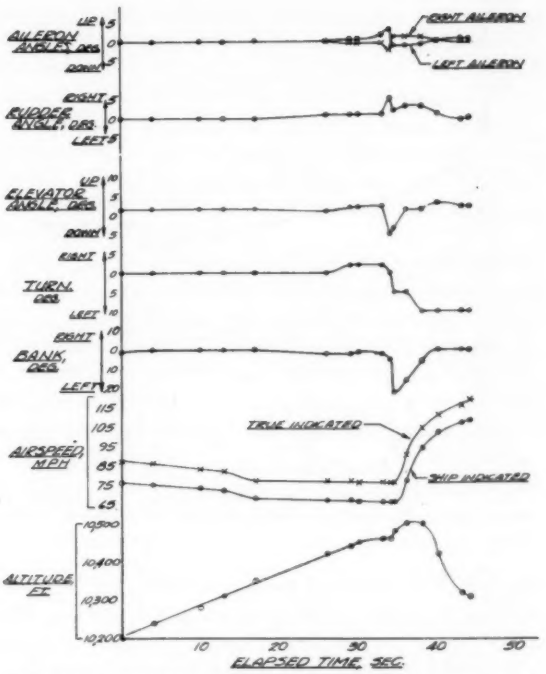


FIG. 12. Stall with power on, flaps up. Stall test No. 14.5; gross weight, 15,314 lbs.; c.g., 31.8 percent; 2000 r.p.m.; 28 in. Hg; landing gear down.

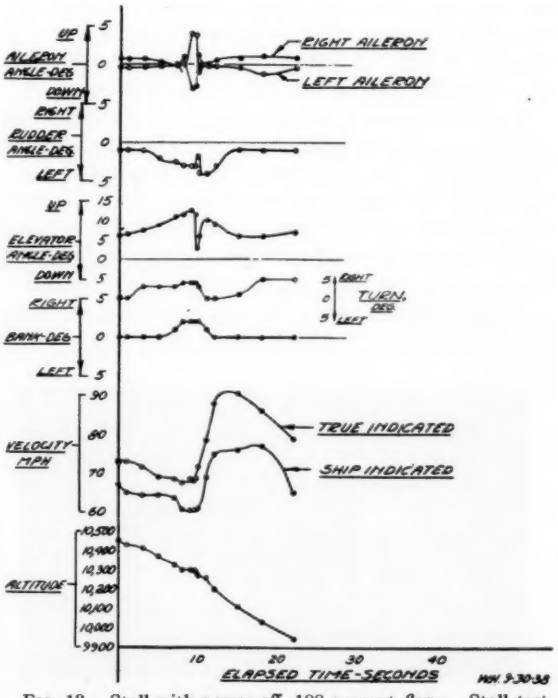


FIG. 13. Stall with power off, 100 percent flaps. Stall test No. 14.4; gross weight, 15,424 lbs.; c.g., 31.8 percent; 900 r.p.m.; landing gear down.

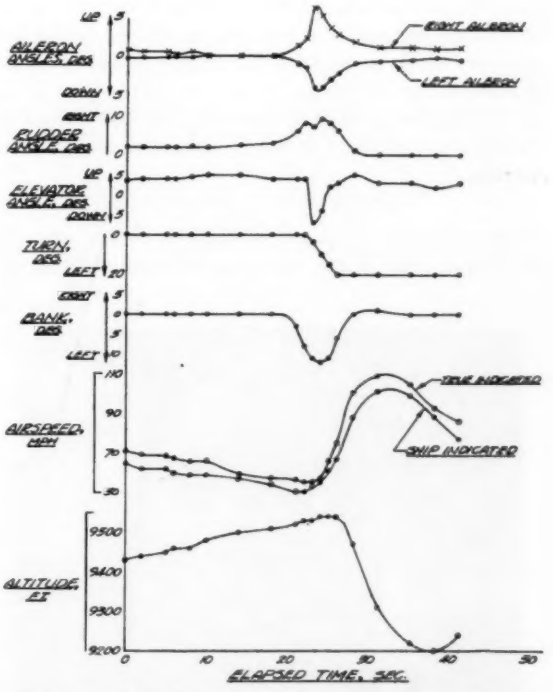


FIG. 14. Stall with power on, 100 percent flaps. Stall test No. 14.8; gross weight, 15,084 lbs.; c.g., 31.8 percent; 2000 r.p.m.; 28 in. Hg; landing gear down.

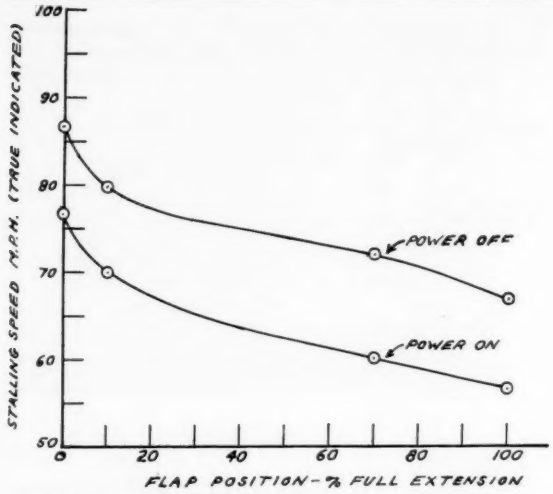


FIG. 17. Stalling speed versus flap settings. Stalling speeds from flight tests; results corrected to gross weight of 15,650 lbs.

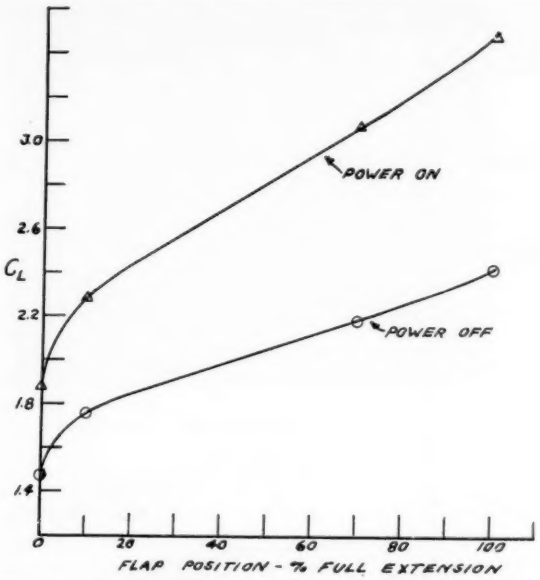


FIG. 18. Maximum C_L versus flap setting. Maximum C_L obtained from stall tests.

edge which is connected to an instrument on the pilot's instrument panel. The pressure at the leading edge of the airfoil is a function of speed and angle of attack. A method has been found to eliminate the speed function leaving a pressure measurement which is a function of angle of attack only. This unit has been thoroughly tested in the wind tunnel and was found to give very accurate readings over a large range of angles and its current development is now in the hands of an instrument manufacturer. It is planned to use the instrument to give both a visual and audible warning to the pilot as he approaches the stall. It can also be used to obtain the optimum angle on take-off for seaplanes and the best climbing angles of attack for any aircraft. The unit is electrically heated to eliminate icing possibilities and its reading is independent of power and gross weight of the aircraft.

WING CHANGES INVESTIGATED

Fig. 21 shows various modifications to the wing tip which were tried in the wind tunnel in an effort to improve the stall characteristics of Model 14. Such items as increasing the airfoil nose thickness, twisting the normal airfoil with a 2° washout and utilizing highly cambered sections with twist were tried in the California Institute of Technology wind tunnel. None of these changes were readily adaptable or particularly effective for the case investigated. The most effective one was the use of the highly cambered section, but when this was used, the moment coefficient was so high that the design tail load exceeded the strength of the tail structure. Hence, this change could not be used.

A flight test was made to determine the effect of the wing tip navigation lights which were located at about 90 percent of the wing span. The removal of these units indicated absolutely no change in wing stalling characteristics. They were, nevertheless, moved to a more outboard position in order to eliminate the effect of ice forming on these units, precipitating the stall.

A flight test was run to determine the effect of changing the wing tip sections only, using a very large amount

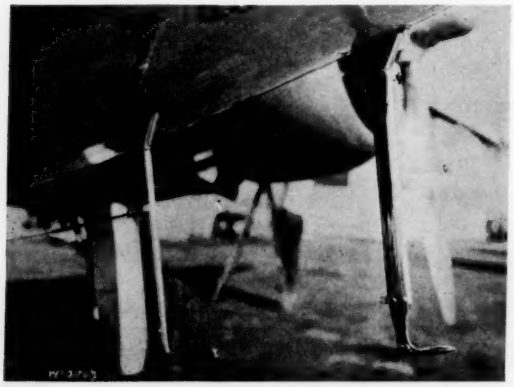


FIG. 19. Angle of attack indicator.

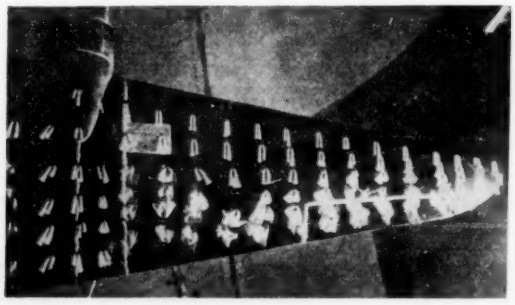


FIG. 20. Upper surface of wind tunnel model during stall.

MODEL 14 WIND TUNNEL MODEL VARIATIONS — AIRFOIL SECTION —	$C_{L_{MAX}}$	C_{D_0}	C_M
STD. N.A.C.A. 23009	1.225	.0100	-.003
N.A.C.A. 23009 WITH MODIFIED NOSE	1.240	.0102	-.010
* N.A.C.A. 23009 + 3½° TWIST	1.220	.0104	-.010
N.A.C.A. 4412 + 2° TWIST	1.28	.0115	-.021

* VALUE OF AIRPLANE EFFICIENCY FACTOR "e" DECREASED SUBSTANTIALLY

STATIONS SHOWN ARE 93% OF SEMI-SPAN

FIG. 21. Wing changes tested in wind tunnel.

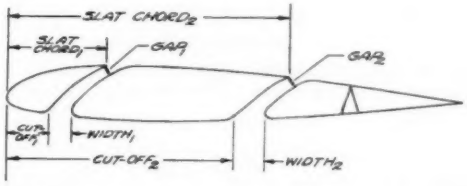
of twist and a great change of airfoil section. All the effects of changes in the tip only seem to aggravate the stalling condition rather than help it.

FIXED SLOT TESTS

The last device investigated was the use of fixed slots cut into the wing itself. All other airfoil changes had given either very little effect on the stall characteristics or an excessive moment, when effective. It is known that the fixed wing slot produces a slight stalling moment which tends to relieve the design tail load. Structurally, the fixed slot is ideal in that it causes no change in the normal wing lift distribution below the stall. An investigation was made of 16 combinations of leading edge and aileron slots in an effort to obtain the optimum effect on the tip stall condition and on the drag.

Figs. 22 through 24 give the dimensions and locations of the slots tried. It is realized that the icing problem with the fixed slot is one to be carefully considered, but at the present time, indications are that, should the slot be completely sealed by ice, the aircraft will be no worse off than it would be without the slots. Actual flight tests will soon begin under simulated icing conditions to determine the effect of ice on the wing slot and aileron control. Until the results of these tests are obtained, it is not known whether or not rubber deicing boots must be fitted to the slots.

The final configuration of slots chosen consists of five separate sections extending between rib stations in the manner shown in Fig. 23. The arrangement chosen is optimum from a structural viewpoint as well as from an aerodynamic one in that only 9 percent of the wing area is affected and none of the main structural members are cut. About 90 per cent of the slot effectiveness is produced by the four inboard slots, the tip section being effective only in adding a slight amount of aileron control. The effect of the fixed slots on drag and other performance items is almost negligible. Fig. 30 shows the flight test results on airplane speed. The reason for the small effect is that although the slots probably double the drag of the wing section immediately behind them, the percentage of this area to the total wing area is so small that there is little effect on the speed and climb. A decrease of single engine ceiling of only 330



STA., IN.	CHORD1 IN.	S.C.1 % C	S.C.2 % C	C-O1 % C	C-O2 % C	GAP1 % C	GAP2 % C	WIDTH1 % C	WIDTH2 % C
264	80.22		65.7		50.7		2.6		6.9
276	76.35		65.3		50.6		2.6		6.7
289	72.16	21.0	64.5	8.2	50.4	1.7	2.6	3.7	6.6
302	67.97	21.2	63.7	8.6	50.3	1.6	2.6	3.7	6.4
315	63.78	21.3	62.8	9.0	50.2	1.6	2.6	3.8	6.4
328	59.59	21.6	61.9	9.4	49.9	1.7	2.8	3.9	5.8
341	55.28	21.8	61.0	9.8	49.8	1.8	2.9	3.8	5.6
354	49.81	22.6	61.3	10.7	51.1	1.9	2.9	4.0	5.4
363	45.08	22.5		11.0		2.2		5.5	
373	38.19	23.1		12.2		1.8		4.6	
383	27.46	20.3		10.0		2.4		4.6	

FIG. 23. Cross-section of slotted wing; 1401 wing slots.

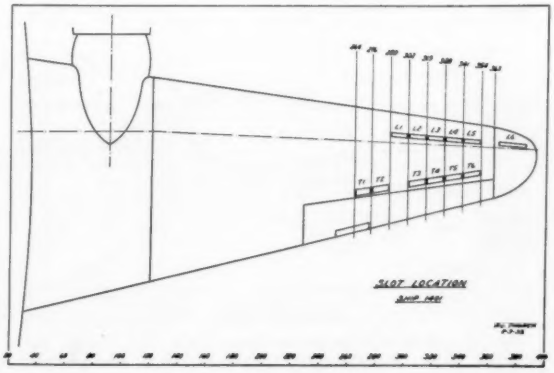


FIG. 22. Slot locations.

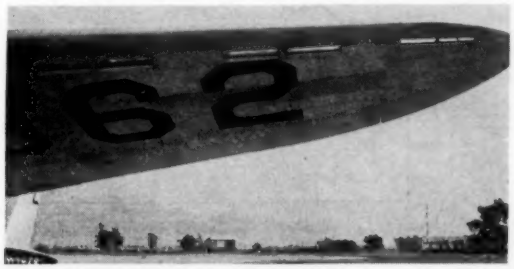


FIG. 24. Photograph of the slotted wing.

feet is obtained with the slots open compared to the same performance item with them closed.

The effect of the slots on the stall characteristics is very marked for all important stalling conditions. In the landing configuration with any amount of flap setting with power off, or with normal approach power, the airplane has no tendency to fall off on a wing. Aileron control exists at angles of attack above the stall

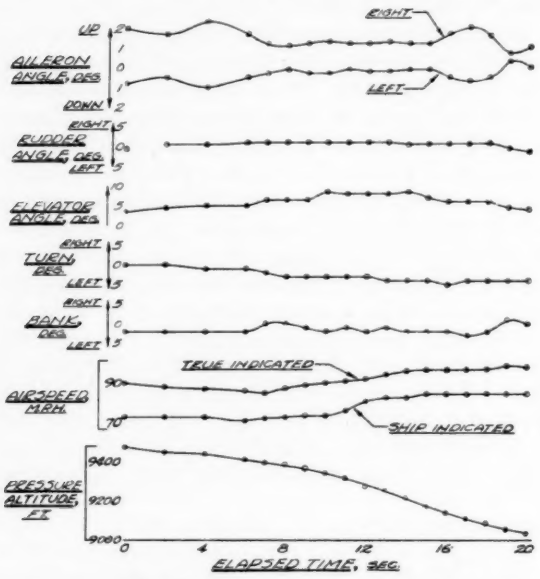


FIG. 25. Stall with power off, flaps up, with slots. Stall test No. 18.95; gross weight, 14,730 lbs.; c.g., 30.5 percent; landing gear down.

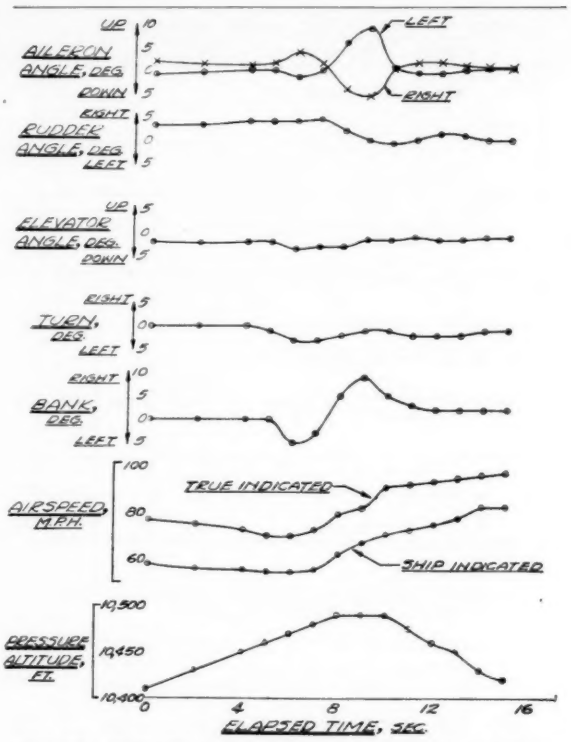


FIG. 26. Stall with power on, flaps up, with slots. Stall test No. 18.2; gross weight, 15,580 lbs.; c.g. 30.5 percent; landing gear down.

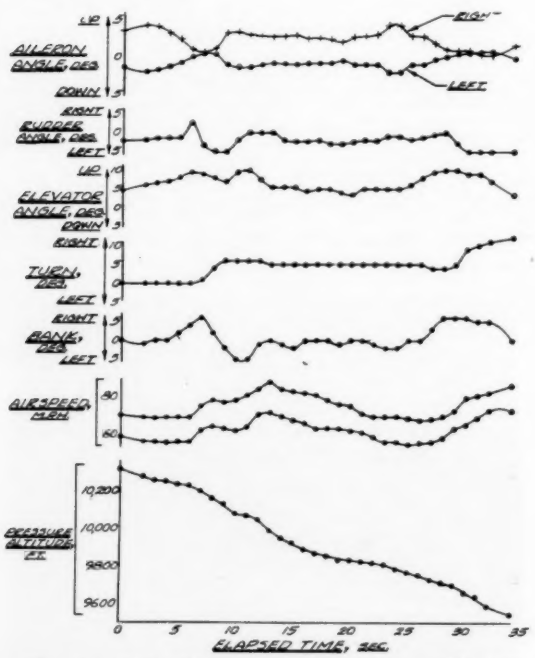


FIG. 27. Stall with power off, flaps down, with slots. Stall test No. 18.9; gross weight, 15,120 lbs.; c.g., 30.5 percent; landing gear down.

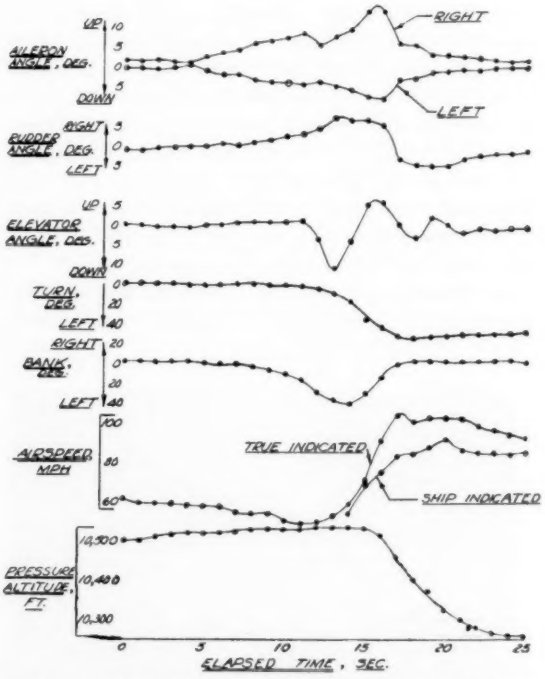


FIG. 28. Stall with power on, flaps down, with slots. Stall test No. 18.91; gross weight, 15,040 lbs.; c.g., 30.5 percent; landing gear down.

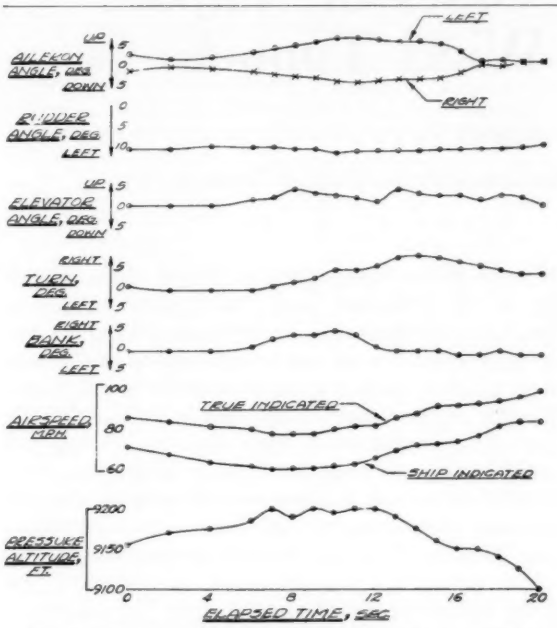


FIG. 29. Single engine stall with slots. Stall test No. 18.94; gross weight, 14,820 lbs; c.g., 30.5 percent; 2000 r.p.m.; 26 in. Hg; landing gear down.

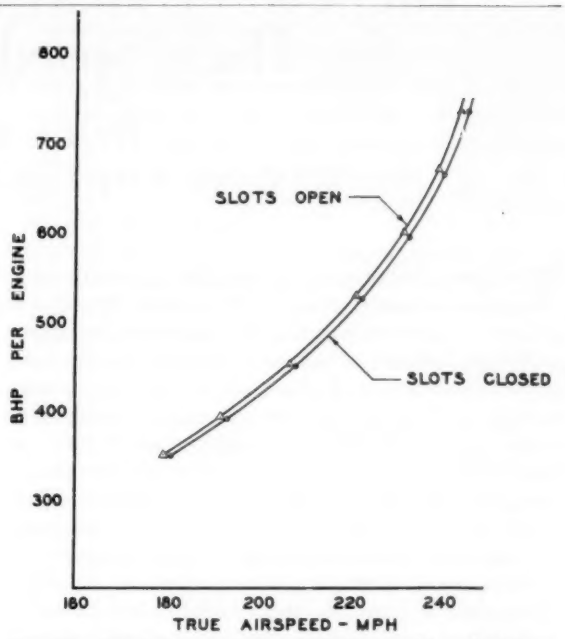


FIG. 30. Speed characteristics of Model 14 with and without slots.

particularly with the wing flaps fully extended. For the take-off condition with full power on the flaps retracted, the airplane can be flown and climbed in the stalled contion holding the wings level by use of the ailerons. The airplane now gives warning of the approach to the stall in all conditions of take-off and landing beginning about 7 m.p.h. above the stalling speed. Considerably greater stick motions are required for stalling, and aileron control at speeds below 110 percent of the stalling speed is considerably improved. Figs. 25 to 29 give comparative data on the different stalling conditions with the slots in use. One condition still remains unchanged from that which existed with the original wing; only slight improvement exists for the condition of flaps down with power on. No combination of slots tried gave much control of the flow over the tip sections for this case. A high rate of roll still exists if the airplane is stalled with full power on and the wing flaps down. It should be noted, however, that the stalling speed for this condition with the flaps fully extended occurs at about 53 miles per hour true indicated speed, which is below the reading of the airspeed indicator in the airplane. Such a high angle of attack must be reached at such a low speed that it is considered very unlikely that this condition should ever give rise to trouble in service. One of the best stalls which the airplane now makes is obtained when flying on one engine. This was previously a very dangerous stall, but with the slots open, the airplane has no tendency to fall off on one wing (see Fig. 29).

It should be mentioned that in trying the various slot combinations, many were tried which improved the power-off characteristics somewhat, but which showed no improvement for the take-off condition. The wing slots finally used were easily adaptable to airplanes already in service at very little expense or labor, the installation being made within three days.

CONCLUSIONS

The foregoing investigation has brought out many factors which will be of great influence on the design of subsequent airplanes. The methods used and the equipment developed have proved very satisfactory in all respects for measuring stall phenomena as well as general stability and control factors. The use of fixed wing slots was thoroughly justified for the case investigated, although it is believed that in the design of a new airplane, certain elements can be embodied which will give equally good stall characteristics at even less cost in drag; or the wing slots themselves can be improved in design and arranged to be closed during normal flight so that even an airplane with good stalling characteristics could be improved by the use of the fixed slot unit.

The Use of Heavy Gases or Vapors for High Speed Wind Tunnels

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THE importance of the investigation of aerodynamic phenomena at High and at Supersonic Velocities is evident. However, it is not yet imperative enough to justify the building of tunnels with large cross-sections or continuous action, because of the high cost of construction and operation. Instead, most investigations in this field are carried out by means of wind tunnels of small cross-section, depending upon an accumulator of compressed air or a vacuum tank. A relatively small compressor or vacuum pump is sufficient for intermittent operation of the wind tunnel. Such arrangements, however, while answering their purpose to a certain extent, are far from the ideal solution. The intention of this paper is not to give such a solution, but to make a contribution to this difficult and complicated problem by approaching it from another standpoint.*

All experiments with models are carried out on the basis of Dynamic Similarity and, in finding the effects of compressibility, it is necessary to take into account the Mach Number V/C, where V is the velocity of the fluid in which the model is placed and C is the velocity of sound in the same fluid. This condition requires that the speed of flow be practically the same in the model test as it is under actual conditions. However, if gases or vapors other than air are used it would be possible to change the value of C and thus operate at smaller velocities while maintaining the same Mach Number. Of course, such experimentation would require an airtight tunnel, and the operation of this tunnel, similar to that of a Variable Density Tunnel, would require remote control for all apparatus inside the tunnel, and in the case of certain compounds, might require temperature conditioning. In addition to this there must be a special arrangement allowing replacement of models in the tunnel in a short time without admitting air or allowing the gas to escape, and another arrangement for the collection and storing of the gas and for its purification (from air, water vapors, etc.). All of these extra difficulties are compensated for by a saving in power, providing heavy enough gases are used.

Several factors must be taken into consideration in selecting the substance to be used as a flowing medium. It must have a high Molecular Weight, since, according to the Avogadro Law, the density of gas or vapor is proportional to its Molecular Weight. The speed of sound in a gas can be expressed by the formula $C = \sqrt{\gamma P/\rho}$, where γ is the ratio of the specific heats, P is the pressure, and ρ is the density. From this formula it is seen that for the same values of γ the speed of sound is inversely proportional to the square root of the density and so can be considered to be approximately inversely proportional to the square root of its Molecular Weight. It is also directly proportional to the square root of γ. γ can be found experimentally with great accuracy from determination of the velocity of sound in the gas (or vapor) under consideration. It is known from the Kinetic Theory of Gases and by actual measurements on argon, helium, and mercury that for monatomic gases the value of γ is 1.67. The mean value of it for diatomic gases is about 1.4; for polyatomic gases γ is less than 1.4 and varies through a wide range for different substances. The values of the speed of sound for different values of the Molecular Weights and γ are given in Table 1.

TABLE 1

Sound Velocities. (Meters per sec.)

Mol. Weight	$\gamma = 1.4$	$\gamma = 1.3$	$\gamma = 1.2$	$\gamma = 1.1$
100	178.3	172	165	158
120	162.8	157	151	144.5
140	150.7	145	139.5	134
160	141	136	131	125
180	132.9	128	123	117
200	126.1	122	117	112
250	112.8	108	104.5	100
300	103	99.4	95.3	91.3
350	95.3	91.8	88	84.5
400	89.2	85.8	82.6	79
450	84.1	81	77.8	74.5
500	79.7	76.7	73.7	70.7

The other important property required is that the substance must be in the gaseous state under the normal conditions of the experiment, *i.e.*, its boiling point must be within the normal test conditions. It is a regrettable fact that the boiling point of compounds usually rises with increase of Molecular Weight. This relation is so definitely manifested, especially in the case of the members of a homogeneous series of compounds, that there is a growing tendency among chemists to express this relation with the help of mathematical formulas.

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* The author desires to express his thanks to Dr. Heinrich Peters, Prof. Joseph Keenan and Mr. Brandom Richtmire with whom he consulted on several occasions. He also is deeply grateful to Harvard University for permission to use the Widener Library.

TABLE 2

Percent of the power output required to produce a fluid flow of heavy gases as compared with that for air. *A*—for the same density; *B*—for the same force effect on a model (supposing the force reaction to be proportional to the square of velocity) for the same Mach Number.

Molecular Weight	$\gamma = 1.4$		$\gamma = 1.3$		$\gamma = 1.2$		$\gamma = 1.1$	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
100	15.6	28.9	14.1	27.0	12.3	24.8	10.9	22.8
120	11.9	24.2	10.6	22.5	9.5	20.9	8.3	19.1
140	9.4	20.7	8.4	19.2	7.5	17.8	6.6	16.4
160	7.7	18.1	6.9	16.9	6.2	15.7	5.4	14.3
180	6.5	16.2	5.8	15.0	5.1	13.8	4.4	12.5
200	5.5	14.5	5.0	13.5	4.4	12.5	3.9	11.4
250	3.9	11.6	3.5	10.6	3.2	10.0	2.8	9.1
300	3.0	9.7	2.7	9.0	2.4	8.2	2.1	7.6
350	2.4	8.2	2.1	7.7	1.9	7.0	1.7	6.5
400	1.9	7.2	1.7	6.7	1.5	6.2	1.3	5.7
450	1.6	6.5	1.5	6.0	1.3	5.5	1.1	5.1
500	1.4	5.8	1.2	5.3	1.1	4.9	0.97	4.5

To these conditions for selecting the substance must be added that the substance sought must be chemically stable and inactive in relation to the materials of which the tunnel, apparatus, models, and propelling machinery are made, as well as to the air and water vapors which are always present in air. It is also desirable that it be non-inflammable, non-poisonous, not very toxic, not very expensive, and easily purified.

When one examines chemical substances of high Molecular Weight and low boiling point, which are comparatively chemically stable and not dangerous, one does not find many from which to select. Among elementary substances there are such heavy gases as Xenon and Krypton. Both are inert gases found in the atmosphere, but in such negligible quantities that their use for wind tunnels is quite out of the question. The other elementary substances like mercury, bromine, and iodine do not satisfy the above requirements and one must look rather for organic and inorganic compounds.

There are such compounds as $C_2F_2Br_4$, $C_2F_3Br_3$, $C_2HF_2Br_3$, $CFBr_3$, $C_2Cl_3F_3$. All have very high Molecular Weights. The substitution of hydrogen by fluorine lowers their boiling point and usually increases the resistance to dissociation. But, in order to decide about the possibility of their use as a flowing medium in a wind tunnel, it is necessary to make a special and more detailed study of their different properties. $C_2Cl_3F_3$, Trichlorotrifluoroethane, occupies a particular place among them. It belongs to the group of so-called freons used in refrigeration. The members of this group are non-corrosive, non-irritating, non-toxic, and stable (if not exposed to open flames or to a sufficiently hot surface). This compound may be recommended for the further investigation of the possibility of its use for wind tunnels.

A special group is formed by compounds with silicon (such as $Si_4O_3Cl_{10}$, $SiBr_4$, $SiClBr_3$, Si_2Cl_6O, $SiCl_2Br_2$, $SiCl_3Br$). These compounds, being similar to those formed by carbon also have high Molecular Weights and comparatively low boiling points, but our knowledge of these compounds is incomplete and the subject appears scarcely to have been investigated since 1881. Like all silicon compounds they can be used only when isolated from all water vapor.

CCl_4, Carbon Tetrachloride, merits special attention. Its Molecular Weight is 153.8 and its boiling point, 76.65°C. It is a product widely used for various industrial purposes and is manufactured cheaply in great quantities. Its properties are well known and its use for supersonic wind tunnels may be definitely recommended. There are also other compounds similar to Carbon Tetrachloride, such as C_2HCl_3, CCl_2F_2, $CHCl_3$ (Chloroform), $C_2H_3Cl_3$. They also are widely used in industry but their Molecular Weight is lower than that of CCl_4.

SF_6, Sulphur Hexofluoride, stands apart for its physical and chemical properties. It is a remarkably inert gas. Its Molecular Weight is 146.06. Its use might be strongly recommended, if it could be manufactured inexpensively. Only one objection may be made against the use of this compound: Its low boiling point (−62°C.) would make difficult the elimination of air from it. This is, however, not a very serious objection and if a practical way of producing this compound can be found it may serve as one of the best mediums. C_2F_6, Hexafluoroethane, is similar to this compound in some respects.

It must be emphasized that the final selection of one compound or another depends not only upon the requirements for use in the wind tunnel but also upon the financial consideration.

In the case of compounds with rather high boiling points a combination of several of them would produce a higher total pressure at the same temperature than does one individual substance. Hence, the use of such a combination might produce a fluid convenient enough to handle, at the same time possessing a high density and, consequently, a low sonic velocity.

THE HEAVY VAPOR WIND TUNNEL

A preliminary investigation of general thermo- and aerodynamic conditions governing the design of a supersonic heavy vapor wind tunnel is given here, for the purpose of illustrating the application of the general principles of such a design, without entering into details.

Carbon Tetrachloride was selected as the flowing medium. It is not the only compound which may be recommended for use, but is selected because more complete physical and thermodynamic data are available for this compound than for certain others.

The velocity of flow was chosen as 650 ft. per sec., permitting a Mach Number of 1.3. The area of the

experimental cross-section was taken as one square foot. The flow was supposed to be adiabatic with friction, except for the portion where cooling was introduced. The experimental section is followed by the diffuser in which adiabatic compression with a 30 percent loss is assumed. The compression is carried by the axial flow six-stage fan compressor. A minimum of six stages of compression is required because of the low sonic velocity of carbon tetrachloride vapor. This sonic velocity definitely limits the circumferential fan and axial fluid velocities.

The thermodynamic properties of CCl_4 are presented in Tables 3 and 4. The data were collected from references (1). Some of the values, after adjustment, were used directly, the others were derived by computation from given values. In some cases the values given were various and even contradictory; those most frequently cited and those which agreed best with general thermodynamic relations were selected. The Temperature-Entropy Diagram (Fig. 1) with equal enthalpy lines was plotted from data of Table 3.

TABLE 4. THERMODYNAMIC PROPERTIES OF CARBON TETRACHLORIDE

Temperature, Pressure, Specific Volume, and Enthalpy of vapors at the Points A, B, C, D_1, and D_2 in Fig. 1 (computed).

Point	Temperature °F.	Pressure Lb. per Sq.In.	Specific Volume Cu.Ft. per Lb.	Enthalpy B.t.u. per Lb. 1°F.
A	145.7	6.68	6.55	116.9
B	90	1.86	19.70	108.5
C	144	4.18	10.27	116.76
D_1	180	6.84	6.87	...
D_2	181	6.90	6.81	...

Specific Heat of vapors at constant pressure, C_p

Temperature °C.	C_p B.t.u. per Lb. 1°F.	Source
	0.156*	Refrigerating Data Book, 1934-36
0	0.140	International Critical Tables
30	0.132	International Critical Tables
70	0.115	International Critical Tables

* The first value, 0.156, was used in plotting the Temperature-Entropy Diagram as it satisfies better the general thermodynamic relations.

Conditions of the Flow through the Wind Tunnel

In the following examination the Temperature-Entropy Diagram served as a basis on which selection

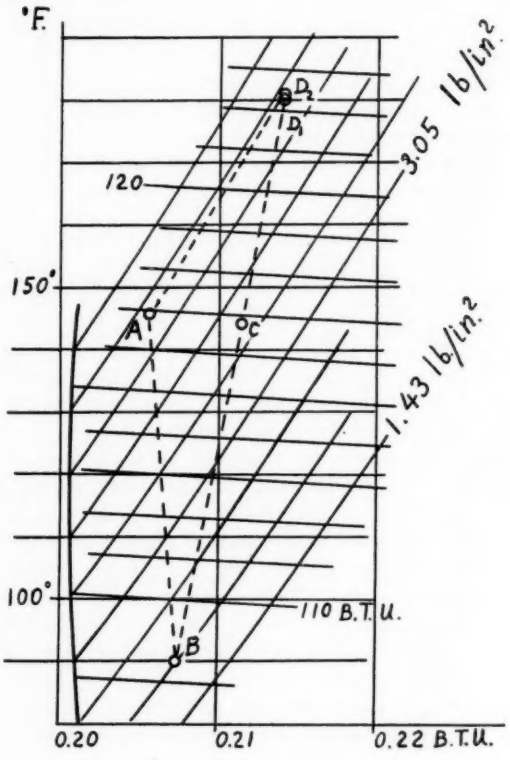

FIG. 1.

TABLE 3

Thermodynamic Properties of Carbon Tetrachloride Liquid and Saturated Vapors

Temperature °F.	Pressure Lb. per In.	Sp. Vol. Cu.Ft. per Lb.	Total Heat Liquid	Total Heat Latent	B.t.u. Vapor	Entropy Liquid	B.t.u. Vapor
30	0.60	52.8	5.70	93.70	99.40	0.0121	0.2034
40	0.81	40.0	7.70	93.18	100.88	0.0168	0.2030
50	1.08	30.6	9.78	92.61	102.39	0.0210	0.2026
60	1.43	24.0	11.88	92.02	103.90	0.0250	0.2020
70	1.86	19.0	14.00	91.41	105.41	0.0291	0.2016
80	2.40	15.3	16.14	90.77	106.91	0.0331	0.2012
90	3.05	12.4	18.32	90.09	108.41	0.0371	0.2009
100	3.83	10.2	20.54	89.38	109.92	0.0411	0.2007
110	4.78	8.5	22.78	88.65	111.43	0.0450	0.2005
120	5.89	7.1	25.06	87.88	112.94	0.0490	0.2005
130	7.20	6.0	27.40	87.14	114.44	0.0530	0.2006
140	8.71	5.2	29.75	86.32	115.94	0.0570	0.2008

of the starting point and examination of the thermodynamic processes of the flow was carried out. The process of cooling was considered to go almost along an isobaric line (with a very small drop of pressure). The specific volumes of superheated vapors were computed from $PV = RT$ for ideal gases, as it was found that, for the low pressures used, the difference between the values found by this equation and those computed by van der Waals' equation is a negligible quantity.

Nozzle, Experimental Section and Diffuser

The point B on the Entropy Diagram was selected to define the conditions at the Experimental Section. It gives the temperature 90°F., the pressure 1.86 lbs. per sq.in., the specific volume 19.70 cu.ft. per lb., the enthalpy 108.55 B.t.u. per lb. 1°F., and superheating 20°F. If the velocity at the experimental section is 650 ft. per sec. and the velocity of approach is 71 ft. per sec., the corresponding kinetic energies of the flows are 8.45 B.t.u. per lb. and 0.1 B.t.u. per lb., respectively. These values, together with the assumed 10 percent loss in adiabatic expansion, define the point A on the diagram. This point determines the conditions of the flow at the entrance of the nozzle. (See Table 4.) The losses in the experimental section together with the friction losses in the diffuser are assumed to be 30 percent. This locates the point C at the end of the compression in the diffuser.

Fig. 2 is a diagrammatic sketch of the tunnel and fan for the flow of 33 lb. per sec., corresponding to a velocity of 650 ft. per sec. through a 1 ft. square section.

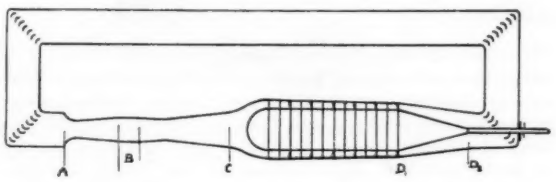

FIG. 2.

Compressor

The points D_1 and D_2 on the chart are determined by the assumption that the compression is adiabatic with a 30 percent loss. An axial flow fan is selected as a compressor, with the guide vanes ahead of the fan discs. As stated above, six stages are required and constant axial velocity through the compressor is assumed. Since a comparatively high rise of pressure is required from the compressor this necessitates high velocities of rotation and of axial flow, while, on the other hand, care must be taken that the tip speed does not approach that of sound. This condition determines the starting point of the design by finding the limits of the velocities in the fan.

The approximate formula for the maximum local velocity,

$$V_{loc.max.} = V_0(1 + C_L/\pi)$$

where V_0 is the relative velocity of the flow, and C_L is the lift coefficient of the blade profile, is used for determining the propeller tip speed. The sound velocity at the temperature considered is about 492 ft. per sec. Hence, if the maximum Mach Number for the local velocity is taken as 0.9, the relation above gives the value of $V_{0\,max.}$ equal to 352 ft. per sec., if C_L is equal to 0.8. The basic formula governing the design may be given by Euler's equation in the form: $g\Delta H = C_y U$, where ΔH is the "Heat Rise" per stage of compression per unit weight of the fluid (in energy units), C_y the tangential component of the absolute velocity of approach (after passing through the fan the flow is assumed to be purely axial) of the fluid, and U the circumferential velocity of the blade element under consideration. This equation can be used to investigate what value the circumferential and axial velocities must have to produce the required compression.

As was stated above 30 percent is assumed to be lost in the compressor and this value was considered in finding the line CD on the entropy chart. After the preliminary considerations are made and approximate values of the velocities and of the dimensions of the fan are determined, the detailed computations of the losses would bring the corrections and necessary refinements into the design.

Three factors must be considered to determine the velocity of rotation and of the axial flow: (1) the upper limit of the velocity V_0 (equal to 352 ft. per sec.), (2) the number of the stages n and (3) the total rise of heat H to be produced by the compression. From geometric considerations (Fig. 3) of the relation between velocities it follows:

$$V_0^2 = U^2 + C_y^2 + 2UC_y + C_y^2 \operatorname{Cot}^2 \beta$$

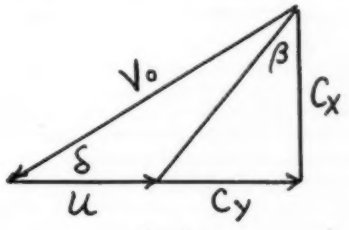

FIG. 3.

where β is the angle of deflection of the axial velocity C_x in the guide vanes at the entrance of the fan. The value of UC_y and C_y can be substituted from Euler's equation. Let q denote gH/n, then

$$u^2 = \frac{V_0^2 - 2q}{2} \pm \sqrt{\left(\frac{V_0^2 - 2q}{2}\right)^2 - q^2(1 + \operatorname{Cot}^2 \beta)^2}$$

The examination of this equation shows that a proper value of q has to be substituted in it in order to obtain real roots. As q depends on n this determines the minimum value of n. It is somewhat simpler to proceed by the trial and error method assuming different

values of n and C_x and finding U and V_0. The value of V_0 must be equal to or less than the maximum (352 ft. per sec.). Usually a few trials are sufficient to test the selected values. It was found that six stages are required to satisfy the conditions. This determines the value of C_yU. It is equal to 23,000, in ft., lb., sec. units. The selected value of C_x is 110 ft. per sec. and this determines the values of U, V_0, β, and δ at the entrance of the fan. They are 209 ft. per sec., 319 ft. per sec., 45°, and 19°, respectively, at the tip of a blade and 146.5 ft. per sec., 340 ft. per sec., 55°, and 18° 50′, respectively, at the hub of a blade, for a hub-diameter ratio of 0.7. As the axial velocity of the flow through all stages of the compressor is assumed to be the same, the fan discs are not followed by the diffusers and so the consideration of the diffuser influence on the output of the fan is absent and examination of losses is reduced to the consideration of the "hydraulic losses" and those of friction in the guide vanes and casing. The "hydraulic losses" under the chosen conditions amount to approximately 5 percent.

The values of the velocities, specific volumes of the fluid and the selected hub-diameter ratio (0.7) determine the dimensions of the compressor. The angular velocity of rotation is found to be equal to 151, the number of revolutions is 24 per sec. or 1440 per min. The total power required for the work of the compressor is equal to the increase in heat in the compressor per pound multiplied by the quantity of the fluid flowing per second. It amounts to 263 hp. The "overall efficiency" of the tunnel is equal to 1.5. (The losses in the conduit between the compressor and the nozzle are assumed to be 250 percent of the kinetic energy of the flow in this part of the tunnel.)

In conclusion it must be said that this investigation is not a complete analysis of the problem; its purpose is limited to an outline of the main points in the design and to the illustration of the practical feasibility of the project. Instead of the multi-staged axial flow fan, an ordinary turbo-compressor may be used. In this case it would be possible by using the cooling in the compressor itself to make the thermodynamic process of compression more efficient than the adiabatic one, but this advantage may be eliminated by the greater friction losses and turbulence to be expected in a turbo-compressor.

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Book Reviews

Aircraft Engine Maintenance for the Engine Mechanic, by Daniel J. Brimm, Jr., and H. Edward Boggess; Pitman Publishing Company, New York, 1939; 470 pages, $2.50 (lithographed).

The purpose of this book is to present the fundamentals of engine construction, operation and maintenance in a form which may be readily grasped by a beginner. Reference material which should be of value to an expert mechanic is also included which makes the book rather broad in scope.

In the presentation of subject matter the authors have greatly enriched each chapter by an abundance of photographs and drawings. In the case of the more complex engine and accessory assemblies, copies of the manufacturers' original plates and drawings have been reproduced, thereby insuring accuracy and authenticity.

An endeavor has been made to present the subject in the form of a training manual or text, and all chapters are broken down into divisions and sub-divisions, each sub-division being considered as a unit of work. Whenever possible a graphical presentation or illustration is given, an example is stated and the problem solved.

The various chapters of the book are complete in themselves and a definite subject can readily be identified and selected from the table of contents. The chapters are both numerous and broad, covering basic subjects, principles, and systems.

Owing to the fact that we find complete chapters devoted to such items as fuel systems, carbureter and induction systems, propellers and power plant installation, the book might be referred to as a text or manual on aircraft power plant maintenance.

The book should make a valuable addition to the library of an engine mechanic, student engineer, or any person studying or actively engaged in the operation, servicing or maintenance of engines or aircraft power plants. It is quite up to date and covers many of the most modern accessories, such as hydromatic full feathering propellers, hydro, mechanical, and electrical controllable pitch propellers, gas and inertia starters, automatic power and mixture control unit and late model carbureters.

The authors are to be complimented on the material presented, the method of presentation, and the large amount of detail covered.

Herbert Marsh
Boeing School of Aeronautics

Jahrbuch der Deutschen Akademie der Luftfahrtforschung, compiled by Walter Boje and Karl Stuchtey; R. Oldenbourg, München and Berlin, 1939; 247 pages, 12 RM.

The first 175 pages of this beautifully bound book are taken up with biographical sketches of the members of the German Academy of Aeronautical Research, comprising many of the distinguished aeronautical specialists in Germany and other countries.

The remainder of the book is given over to proceedings of the Academy meetings for the period 1937–1938. Thirteen short papers on high altitude and high speed flight, helicopters, engines, fuels and oils, radio waves, and physical problems are given. These are, for the most part, interesting discussions of recent advances and predictions for the future, rather than detailed investigations of particular problems.

An Analysis of the Problem of Ice on Airplanes

WILLIAM C. GEER
Ithaca, New York

DURING the past twelve years, the author has studied the airplane ice problem with special reference to airline transports, the parts of them which accumulate ice, and serviceable methods for its prevention or removal. The literature upon the subject has become rather extensive and many excellent investigations have been carried out. Yet certain differences of opinion and conflicting points of view have been expressed and a statement of the problem as a whole has not been made. To clarify the subject and to assist any who may study its several phases, it seems wise to prepare this analysis, which has been written primarily from the engineering and research points of view.* Emphasis is given to those fundamental physical aspects which must be built into the design of a protective apparatus and the conditions which it must overcome, if it is to be effective in practice.

Although a number of references to publications are listed, a critical discussion of them all seems inadvisable in the interest of brevity.

I. Atmospheric Conditions

The meterological conditions, which are responsible for those physical states of water in the atmosphere as a result of which it changes to ice when brought into contact with an airplane part, are included in a highly specialized science. A discussion of meterology is outside the scope of this paper. There are many excellent articles in the literature.[1,2,3,4,5,6,7,8,9,10,11,11a,11b]

From an examination of the literature, a study of unpublished tests in a refrigerated wind tunnel, discussions with those who have observed ice during formation, and some direct observations, it seems that the following statements are true and are the more important ones to be taken into account when one attempts the engineering of prevention or removal of ice from airplane parts.

(1) Dry solid water particles (ice particles, hail, or snow) at temperatures which forbid their attachment to any part of the airplane when in flight, do not influence the effectiveness of airplanes.[4,14]

(2) Water droplets of various sizes[2,4,21] may exist in the atmosphere at temperatures below 0°C. They vary in size from less than 0.01 to greater than 1.0 mm. They are thus supercooled and crystallize to solid ice when they come in contact with anything which sufficiently disturbs their unstable equilibrium. Ice may also form directly from saturated or supersaturated air masses.[4,12] Emphasis is given to the droplets since these are more commonly observed, but no clear line of demarcation has been drawn between "clear" (supersaturated) air, fog, light rain, and rain, as to the ice forming capabilities of each. Agreement among investigators[2,16,18] is not general with respect to the several details of temperature, pressure, and other conditions which influence the stability of the supercooled water droplets and the causes of solidification, but they do agree that the temperatures at which ice may form vary over considerable ranges.[4,14,15] Observations have been made from 32° to −2°F.[4] Pilots have found ice at higher and lower temperatures.

(3) Very small droplets[18] possess so little inertia that they may be carried in the windstream just outside the boundary layer[20] and not be solidified upon the airfoil unless they contact some part because of diversion through turbulence or because a part projects beyond the boundary layer.

(4) The time[18,20] required for a given drop to crystallize to ice may be relatively high and only a portion of a given large droplet may solidify instantaneously upon impact[4,16] It may also be assumed that large droplets may be broken into many small ones some of which remain in the windstream.[5]

(5) Because ice may form from large droplets which spread before freezing,[2,4,18] it follows that the ice frequently lies in intimate contact with the surface upon which it has formed even though that surface may be minutely irregular.

(6) Therefore, any measured adhesion of such ice to a perfectly smooth surface will equal atmospheric pressure plus the specific adhesion[24] between ice and the material of which the surface is composed plus what may be called a roughness factor. No measurements of the adhesion of ice to several materials which might compose the surface of an airplane part have been published, although airplane surface irregularities have been studied[58] for an entirely different purpose. However, other things being equal, the rougher the surface the greater the area of contact and the higher will be the force required to separate two materials which have ad-

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hered, provided one of them was applied to the other when in liquid or plastic condition.

(7) The kinds of ice after formation have been classified as rime, glaze (clear ice), and frost which have been described in detail by several authors.[1,2,5,15,20] The physical properties of these types by themselves, when mixed with each other or with water,[2,4] and whether the first formations are continuous layers or isolated pieces, have a direct bearing on details of design apparatus for removal.

(8) The shapes[13] attained by ice formations when allowed to grow, and their positions on wing surfaces, vary somewhat and each influences the C_L and C_D of the plane in a different manner. Explanations have been published,[20] but the engineer is concerned with methods and devices for effective prevention or removal of thin ice layers before a detrimental shape has developed.

(9) The rate at which ice forms on an airplane part varies greatly according to atmospheric conditions and the speed of the airplane.[19] Observations differ over wide ranges from less than 0.5 in. per hour,[4] 2 cm. per minute,[22] and as high as 2 in. per minute.[23] Unpublished pilots' observations have indicated that a rate of 1 in. per minute is not unusual and 2 in. per minute has actually been seen.

(10) The duration of an ice storm and the time during which an airplane may encounter ice vary over wide ranges. Therefore, the total thickness of ice, and the interval during which a protection method may be needed are unpredictable.

(11) Other conditions being equal, small airfoils acquire relatively more ice than do large ones[20] and ice layers on thin airfoils and small sections extend back closer to the position of maximum ordinate at the same angle of attack.

Summary

The foregoing statements lead to one inescapable conclusion: Specifications for the design of methods or devices for the prevention or removal of ice from any airplane part *should not assume moderate limits* for these factors. The scheme should be effective regardless of the atmospheric conditions, size of drops, kind of ice, shape of the layer, or rate of formation of the ice deposit.

II. Theoretical Ideas for Ice Prevention or Removal

Even at the risk of some repetition it seems advisable to consider in principle the several ideas for prevention or removal of ice without reference to the application of them to specific parts of the airplane.

(1) *Non-Wetting Surface Coating*

The simplest theory is that of automatic removal of ice as rapidly as formed from a surface coating, previously applied to the exposed parts, which coating shall be low enough in specific adhesion toward ice so that when formed it will not adhere, but blow off in the windstream. Knight and Clay[25] and Geer and Scott[26] tested surface coatings, but the results were of no practical value. In England a paste called "Kilfrost"[27] has been developed by Halbert and tried on airplanes. Authorities seem to disagree as to its utility.[28]

Any such surface if effective must be aerodynamically smooth, in order to avoid adhesion of ice because of "roughness effect."

The substance must possess a high adhesion to the airplane surface and must be resistant to the abrasive effect of dust, or the sand and cinders of airport surfaces. It must not be cracked, roughened, or worn away by rain and hail which may precede an icing condition.[12]

An ice layer once formed is in intimate contact with the surface and is held to it by atmospheric pressure. Therefore, a surface coating or varnish must be of a character which will prevent drops of water, at any temperature, within this supercooled range, from spreading to a sheet of water which will freeze as a layer of ice. One may visualize a varnish which possess a high negative surface tension, but he cannot imagine a surface of any kind whatsoever which can prevent drops of water from coalescence into streams. Therefore, no surface coating can prevent the formation of a sheet of ice, though it may, however, be loosely held.

(2) *Lubrication of Surface*

A non-freezing lubricant to be applied to a surface either continuously by syneresis from a layer of rubber or by application between flights has been suggested.[26,29] This was partially successful on propeller blades, because there a mechanical force was available, but the quantity of lubricant was insufficient and another method proved to be superior.[37]

(3) *Substances Which Lower the Freezing Point of Water*

A much studied plan has been to spread, continuously over the exposed parts, a liquid which would lower the freezing point of water and so either prevent the supercooled water from crystallizing or redissolve any ice. Solutions of sodium chloride, calcium chloride, alcohol-glycerine,[23] ethylene glycol,[30] and the mixtures of these have been suggested. A number have been tried in wind-tunnel tests and two different liquids are in actual use, one of them in this country upon windshields[23] and propellers,[37] the other in England upon wings.[30] A paste[31] of undisclosed composition has been suggested in England.

Unpublished wind-tunnel tests have shown that ice may form as a cap over the leading edge of a wing section outside a moving layer of glycerine. Observations[32] of pastes during flight have confirmed the foregoing in principle.

Therefore, a sufficient volume of substance must be available and delivered uniformly and rapidly where needed to prevent ice deposition at the most severe rate. For ethylene glycol, alcohol, or glycerine for which freezing point curves of various concentrations in water are available, it is easy to calculate the volume required for any given temperature and rate of ice deposition. The results of these calculations will show that the weights of liquid must be high, relative to payload, if enough is carried to insure protection to a large surface throughout an average flight.

The effect of solutions upon the material of those surfaces with which they may come in contact introduces the problem of corrosion and appearance.

(4) *Heat to Raise the Surface Temperature*

Heat to raise the surface temperature of a given airplane part and so prevent the freezing of super-cooled water has been suggested and studied.

The following discussion applies to heat in principle. It will be taken up later when its application to specific parts is outlined.

Heat would seem to be the theoretically ideal means to prevent super-cooled water droplets from crystallizing to ice in contact with any airplane part, because no change in airfoil surface characteristics is inferred. The source may be the engine exhaust or electrical energy generated for the purpose.

The heat volume and temperature required at the surface depend upon the atmospheric conditions (temperature, ice forming rate, etc.) and heat transfer factors. The latter are subject to calculation by well known methods, but surface temperatures and heat volumes must be worked out experimentally. Some work along this line is now under way.[22,48] It does not follow that any given design of apparatus will successfully protect a part under all situations unless an extreme condition is assumed and a high factor of safety is incorporated into the apparatus. Variable control might be a feature of design, but a risk is involved in that ice conditions and temperatures change rapidly in a way which cannot be anticipated and an added burden of judgment would thus be placed upon the pilot.

The radiators and distribution pipes to enclose hot gases are heavy, as are electrical generators and heating units. The power required to heat large surfaces electrically is an appreciable proportion of that of the motors,[49] although for small areas it may be quite within reasonable limits.

These comments should not be interpreted to mean that heat as a method of prevention should not be studied further. For several of the airplane parts it is a most fruitful subject for research.

(5) *Mechanical Methods for the Removal of Ice after Formation*

A mechanical method or device may be used to lift, loosen, or move a layer of ice before its thickness or shape has reached proportions dangerous to the effectiveness of the part to be protected. The layers should be broken into pieces which blow away in the windstream and thus can cause no disturbance to any following part.

The features of design of a mechanical construction for this purpose are:

Its weight must not be too great. There should be no significant change in the aerodynamic characteristics of the part to be protected. The operation must be prompt and the time cycle must be such that the ice layers may be broken up and blown away at a rate proportional to the rate of formation, or before the accumulation can seriously affect the lift and drag of the airplane.

(6) *Sonic Vibrations*

On the theory that the unstable super-cooled droplets vibrate at a certain resonance frequency, Larsson[17] has suggested sound waves to precede the airplane and cause freezing before the drops can strike the plane. This idea overlooks known studies of elapsed time[18] before drops will solidify.

III. Methods Which Have Been Suggested and Tried

Ice layers may form upon any or all leading surfaces which are exposed to the windstream, and not shielded by other surfaces. Regardless of the means used either to prevent ice formation or to remove it after it has formed, certain parts of the airplane are considered separately, because the effects of ice upon them and the requirements for prevention or removal differ somewhat in each case.

(1) *The Windshield and Windows Exposed to the Windstream*

In this case transparency is a necessary condition, although pilots seem unanimous in the opinion that the entire area of a windshield need not be kept clear. It is preferable, naturally, to maintain a space free from ice throughout the duration of a flight, but while approaching an airport and landing, some completely transparent area must be available.

Several schemes have been suggested.

(a) Clay[33] developed an arrangement of glass plates and cockpit air pressure in such a way that air currents could divert rain drops and leave a free open space through which vision was maintained. He did not study it in ice. These have been tested in England[23,33c] where V front screens also have been tried.

Further study of window design arrangement and air diverting panels is well worthwhile to determine whether there may be any better scheme which, taking into account the aerodynamics involved, may permit any even small area to be clear at all times both in rain and ice.

(b) A rapidly rotating glass disc (the Corry-Kent screen) the speed of which is sufficiently high to throw off any ice as formed, has been considered in some quarters. From the information at hand this has not been tried on airplanes, probably because of the mechanical structure and weight.

(c) Heat, either from electrical resistance wires embedded in duplex glass[34] or by a device within the pilot's compartment to divert hot air against the glass, has been tried. Under some conditions these devices have been successful, but more study needs to be given to this special problem.

(d) A mixture of glycerine and ethyl alcohol well distributed over the glass has been studied and tested in practice. Very little has been published about it.[23] The disadvantage is that the alcohol evaporates more rapidly than glycerine and irregular waves of the latter are left upon the windshield and so vision is far from perfect. Then, too, because the concentration of drops of water in the air may be high, it follows that sheets of ice may form over the glass with a layer of alcohol-glycerine underneath. Such a sheet is prevented from sliding off by the overhanging frame. The chief application of anti-freeze liquid in practice is to remove ice from the sliding windshield panel and permit it to be opened after it has frozen shut.

To improve the action of solutions, the windshield glass should be mounted flush with its supporting frame. Further study of liquids to use in connection with the solution method should be undertaken.

(e) Non-wetting transparent substances have been considered. Here again, no projecting frame should surround the windshield glass. For even if such a surface is extended into the windstream and is free from a projecting frame, it still follows that the edges may be overlapped by the ice sheet and it be prevented from slipping off though the adhesion is negative to a degree greater than atmospheric pressure.

(f) A heavy windshield wiper by itself would seem to lack practical value, because of the force required to break it loose after ice has begun to form. But if some solution to lower the freezing point of water is sprayed on the glass and fed to the blade itself, it might be satisfactory in both ice and rain.

(g) A windshield wiper which may be rotated at speeds up to 2500 r.p.m. about a shaft through a hole in the glass has recently been placed upon the market. Alcohol-glycerine solution is delivered to the rubber blades.

(h) Sliding hoods and "break-open" panels have been suggested.[23] It must not be forgotten that the tensile strength of ice is over 100 pounds per square inch,[35] which, in addition to the wind pressure upon such a panel, would require considerable mechanical force to operate this scheme quickly and effectively.

(2) *Propellers*

Ice forms on the leading edges and thrust faces of the blades, upon the hub, and central parts of the assembly. The situation is specific and unique by comparison with other parts of the airplane, in that a continuously acting centrifugal force is present which tends toward automatic removal of ice layers as formed. The value of the force varies from center to tip of the blade and so over some parts of the span is greater than that of the adhesion of the ice to the material of which the blade is constructed. Thus protection need not cover the entire blade length. However, roughness of the leading edge and thrust faces increases the force required for removal of ice and, because they are irregular, the pieces thrown off are uneven in size. The speed and size of the propeller blade, its material and surface condition are factors which govern the proportion of the length of the blade which must be protected.

Two methods have been tried.

(a) A suggestion was made some years ago which led to a construction[36] consisting of a rubber covered spinner cap over the central mechanism disposed in such a way that the hub for a limited distance was protected from ice. A rubber covering was cemented upon the leading surfaces of the blades part way between the hub and the tip. This rubber was oiled to lubricate it. The idea was that, as fast as ice formed, centrifugal force would throw it off from the lubricated surface. This was only a partial success, and was abandoned in favor of the following scheme.

(b) The mechanism now in universal use was developed under the sponsorship of the Bureau of Air Commerce[37] and with the cooperation of The B. F. Goodrich Company, and Transcontinental and Western Air, Inc.[38,39,40,41] Briefly, this consists of an open ring upon the rear side of the rotating propeller assembly upon which a freezing point lowering solution is fed. This is called a "slinger ring," from which the centrifugal force drives the liquid through feed pipes to the leading edge of each propeller blade.

The solution is a mixture of alcohol and glycerine and in operation it is thrown over a part of the blade in a "flow pattern." The pattern changes with the rate of rotation of the blade, its degree of feathering, and the forward speed of the plane.

This plan is satisfactory although, the distribution of the liquid to the blade and its consequent flow pattern to attain regular and complete ice removal needs some improved plan for the slower speed, longer blades of the new full-feathering propellers.

A continued study of solutions to use in connection with the slinger ring apparatus should be carried on as to rate of lowering the freezing point, speed of flow, pattern of flow, corrosion, and soiling of the material of which the airplane is constructed.

(3) *Wings, Struts, and Other Aerodynamically Shaped Surfaces*

On parts which have airfoil profiles such as wings, struts, and fins, ice forms on both sides of the line of stagnation and caps the leading surfaces. Such a cap of ice cannot automatically remove itself, even though it is loose, for the tensile strength of ice is fairly high[35] and the wind pressures are large enough to hold such a cap in place.

Three methods have been tried or studied.

(a) Pastes and Liquids

The application of pastes[27,31] to prevent ice from forming has already been discussed in principle. Transport planes in England are required to carry one of three kinds of "de-icing equipment," among which is an "approved type of paste."[42] In some aircraft circles pastes are considered to be unreliable safeguards.[28,32,43,44]

Lockspeiser[30] invented and the Dunlop Rubber Company (England) developed a device for the continuous application of ethylene glycol to the leading edges of wings. It has been stated to be successful,[15] but useful only under conditions of mild ice formation rates.[23] It has frequently been discussed in aeronautical literature.[15,23,28,42,43,45] As a carrier for an antifreeze liquid, Bullock in England invented a woven sheet of wire or flax to be placed over the leading edge of wings. It was to be impregnated with a non-freezing liquid.[28]

Neither pastes nor liquids in any form can be considered as reliable or practical means of protection of aerodynamically shaped parts.

(b) Heat

Heat, from the engine exhaust or by means of electrical heating units, has been studied. The advantage of such a plan lies primarily in the absence of alteration of profiles of wing sections.

It was shown experimentally by Theodorsen and Clay,[46] and Scott[47] (by calculations) that theoretically the motors of an airplane lose enough exhaust heat to maintain the leading wing surfaces at a temperature sufficiently high to prevent ice formation or to melt the ice when formed.

Riddle[69] would flow the hot exhaust gases through a pipe in the leading part of a wing and, by a rather elaborate system of air channels, heat the whole wing surface. Theodorsen and Clay[70] pass the motor gases through a boiler to vaporize a liquid which is distributed into the wing.

Brun[22] has studied wing temperatures with special reference to the conditions favorable to a thermic anti-icer. The National Advisory Committee for Aeronautics at Langley Field[48] has studied heat as a means of ice prevention. Ducret and Rideau[34] have patented an electrical heating device, which has been mentioned in the literature.[19,49,51] Work done in England has been described recently.[23,50]

Although the subject of heat as a means of prevention of ice formation has already been discussed in principle it is well to repeat what an engineer who would design a heating system for wings or empennage should consider.

In the refrigerated wind tunnel of The B. F. Goodrich Company at Akron, observations have shown that ice has formed upon a heated surface and because the rate of melting was slower than the rate of ice formation an ice cap over the leading surface of a test wing section was maintained outside a layer of warm water. Therefore, the temperature and heat quantity delivered to the surface must be great enough to melt ice as rapidly as formed and the design of radiators must assume a maximum rate with a generous factor of safety. But should a designer assume 2 in. per minute or should he allow for even higher concentrations?

If leading surfaces only are to be heated as far as, say, 10 percent of chord then the flow-back water certainly will freeze and may form protuberant layers of serious dimensions.

If the entire metal and fixed portions are heated, then the melted ice can flow over and freeze upon the control surfaces, ailerons, rudder, and stabilizers, and the spaces in front of them may even fill with ice sufficiently to prevent operation or interfere with their efficiency.

If the temperature within a heated wing is much higher than the boiling point of gasoline, the heat conductivity of the metal parts will probably be great enough to warm the gasoline tanks, seriously interfering with operation of the motor and introducing a fire hazard. The inference is that any heating system for ice removal must be accompanied by insulation of the gasoline tanks, involving structural changes and weight.

An airplane may need to pass through an ice forming air mass with only one motor in operation. Therefore, both wings should be arranged to permit heating by the exhaust from either motor.

The weight of radiators and distribution pipes; influence upon pay or gasoline load; changes in structure necessary to house them; effect of temperature changes on the strength of the structural members; construction of valves, pipes, and radiators to avoid corrosion; reduction of free flow of gases from the engine exhaust with consequent loss of power; and, probably, other factors as well, render the engineering design of a heat system one of considerable complexity.

Electrical heating suggests generator and heating unit weight, and power loss. One thermo electric device[49] has been calculated to require 25 hp. to heat 10 sq. meters. The wing area of a DC-3 is 91.7 sq.meters and that of a Lockheed 14 is 51.2 sq.meters[68] requiring 229 and 128 hp., respectively.

(c) Mechanical Methods

Details of several mechanical methods for removal of

ice from wings and other surfaces after formation have been published.

Grosselin[51] suggested the use of rollers on rails under a rubber envelope over the leading edge, presumably to deform the sheet and break the ice.

Ängström[17] would provide the leading edge with several layers of cardboard or cellophane. Under each leaf would be a cord along the edge to be pulled by the pilot which would cut the edge and the ice and the layer could blow away.

Bradshaw[52] designed a fine weave metallic matting to be placed over the edge and be deformed by mechanical means.

The mechanical method invented by Geer[53] and developed by The B. F. Goodrich Company has been in practical use for several years.

The Goodrich De-Icer consists of a sheet of vulcanized rubber, backed in part by an extensible fabric to resist tearing, through the forward portion of which are built one or more cavities (depending upon the size of the airfoil) into which air under pressure may be introduced. These cavities, called tubes, run longitudinally along the leading edge. They are connected by tubing within the structure of the plane to an automatic valve to permit periodical timing of inflation and deflation. The valve is connected to an airpump. The De-Icer is applied over the leading surface and extends backward over a predetermined percentage of the chord. The trailing edge is fastened by means of special devices (rivnut and fairing strip) to the wing and, in application, the De-Icer is given an original extension to a calculated percentage of its width. It lies, therefore, flat and taut upon the surface of the airfoil.

In operation, when ice begins to form upon the surface of the rubber sheet, air is introduced at time intervals which have been found by experience to be efficient; the cavities or flattened tubes round out and the sheet between them and the attachment, as well as the sheet of which the tubes are composed, are stretched; the ice while still in thin layers is lifted, loosened, and broken. The tubes are then quickly deflated and the loose ice blows away. The valve to control pressure and vacuum is motor driven at a rate to time the cycle properly and is automatic as far as the pilot is concerned.

These in brief are the basic principles of the Goodrich De-Icer which has been in regular use on transport planes during the past several years and about which much has been written.[17,19,23,26,39,40,41,54,55,56] Hence a detailed description need not be repeated here.

Because the Goodrich De-Icer has been in general use on airline transports, more than passing reference to it is warranted.

(1) It is relatively light in weight.

(2) It is thin, and observations of airplanes in flight have shown relatively little effect upon the speed of the plane or power consumed. No measurements have been published. Doolittle has stated that only a slight effect on speed was observed at 237 mph.

(3) No change is required in the internal structure of wings, for the tubing which connects the distributor valve to the several tubes can be bent around any structural part.

(4) Power required is low.

(5) The width is only that required on account of the position taken by the ice to be removed. This varies with the dimensions of the airfoil section, although some allowances are made for angles of attack. The design is positive with but few uncertainties or assumptions.

(6) The De-Icer may be removed and stored during the summer, and thus its weight changed to payload during the most active transport season.

(7) No assumption as to rate of formation of ice is required, because, theoretically at least, extreme rates may be controlled by variation in the inflation time interval. This statement needs some qualification, in that it is assumed that the pilot will start the inflation cycle at the proper time. Practical experience has shown that the De-Icer removes most ice formations from its surface, provided they are not too wet and the rate of accretion is not excessive. An inference is raised here for the need of an ice detector device especially for "clear" air, although the propeller and windshield may afford some indication of the presence of ice and of its rate of formation.

(8) The ice removed is in pieces which fly back in the windstream and introduce no disturbance to following parts.

(9) Because the sheet is made from vulcanized rubber, the resistance of which to abrasion is probably the highest of any known substance, it affords protection to the leading surfaces from abrasion by hail, sand, and cinders.

(10) Its action may be prompt and positive.

(11) It may be applied to any fixed and some movable surfaces, though it is impractical on very small ones where it may cause vibration.

Some published comments have shown a difference of opinion with respect to certain phases of its action. The Royal Aircraft Establishment[43] considered the De-Icer to be 90 percent effective. The Dutch and Swiss seem to have abandoned them.[71] In this country Frye believed them to be effective[56] although no service records have been published.

Robinson[57] studied, in a high speed wind tunnel, a model built from sheet rubber and wood blocks. The rubber parts were 0.28 scale and the attachment strips at 0.5 scale. He compared his measurements with those of an aerodynamically smooth airfoil, and found drag increases in the conventional installation both deflated and inflated, and bulging under some conditions. None of his models was made precisely like the the commercial De-Icer and so no quotations of his

figures are given. However, changes in surface and attachment strips reduced the drag increases to figures below those recorded by Hood[58] for a rivetted service wing. His comments on bulge (ballooning) should not be taken seriously because he gave no figures on thickness, tension, or composition of the rubber sheet used.

The word "rubber" is a generic term which includes a considerable number of physically different compositions. For instance, and pertinent to the properties of a rubber De-Icer, the stress-strain curves of vulcanized rubber vary greatly for different mixtures, with the dimensions of the test piece, the temperature of test and other factors. A review of those physical and chemical properties of rubber which have a direct bearing upon its utility in ice removal would be outside the scope of this paper. These brief expressions have been made to preface the assertion that no test of a small scale De-Icer model is a reliable guide to full scale effects. Studies of lift and drag should be made only upon models of full scale in section.

Since no measurements of the effect of the De-Icer upon lift, drag, power, or speed of airplanes have been published, research into the influence of the De-Icer as a whole and each part of it upon the performance of airplanes of different designs, may yield data of value. Attachment devices should be studied in order to improve the design with respect to drag and ice accretion, and to permit ice layers to be loosened faster and more easily.

(4) *Ailerons and Control Surfaces*

Aspell[60] has stated the aileron problem clearly: "The accretion of ice on the leading edge of Frieze type ailerons is determined by two factors inherent in the design of an airplane; first, the width of the aileron slot opening on the lower surface of the wing and its cross sectional form, and second, the area of the aileron leading edge which projects below the lower surface of the wing at the aileron slot cut out in flight."

As a result of extended studies in the Goodrich refrigerated wind tunnel upon ailerons and all movable control surfaces, manufacturers generally have redesigned these surfaces so as to afford a maximum of precaution against icing. Details of these studies have been published.[59]

Since these investigations were made no serious icing trouble has been reported upon ailerons or other control surfaces, but the problem should not be abandoned. The ailerons and controls of any new airplane ought to be studied in a refrigerated wind tunnel.

Fixed slots in wings are subject to much the same icing hazard as are the aileron slots. When iced, an unbalanced slot effect may result which can be as serious as the unbalanced control now prevented by modern aileron design. Airplanes of large span might be exposed temporarily to non-uniform spanwise icing conditions which could cause the slots of only one wing tip to freeze.

No trouble, so far as known, has been experienced with trailing edge flaps of any of the several designs. It would be well, however, for engineers to consider the possibility while new models are under study.

(5) *Pitot-Static Tube Supports*

The pitot-static tube and its support present a specialized problem for prevention and removal. Ice on these parts is serious, because the airflow is influenced by the shape, size, and disposition of ice formation. The method of heating the tube electrically[61] is now in use and gives good results, so far as the head alone is concerned. But ice formations upon the strut which holds the pitot head influence static pressures and lead to discrepancies in readings of the instruments operated from it. A window to allow the pilot to observe pitot strut ice would assist greatly in noting formations in flight and would make interpretation of observed instrument readings more reliable. Much of the loss of air speed and altitude in ice can be traced directly to false readings. This may be proved by reference to a suitable emergency static line unaffected by ice.

(6) *Radio Parts*

The protection of exposed radio parts is complicated by the small size and different shapes of the aerials used for sending and receiving. Antenna wires,[62] small and large loops, housed loops, and supporting antenna masts present quite different problems.[23] It is known by observation and record that ice collects in relatively larger layers on small, than it does on large streamlined parts. This causes vibration and in the case of supports, the ice grounds the aerial to the metal of the plane. The metal shapes must be insulated and be free from vibration which would be caused by relatively large removal devices. In England some studies have shown the advantage of fore and aft aerials with shielded supports.[23]

A systematic research into this phase of the ice problem should be undertaken.

(7) *The Carburetor*

Failure of carburetors due to ice no longer need occur. The clogging of valves and passages are caused usually by conditions other than those elsewhere discussed in this paper. It is believed that this phase of the airplane ice problem is too highly specialized for review here. Carburetors which give no trouble are now in common use. There are a number of descriptive articles on the subject.[23,39,41,63,64,65,66,67]

(8) *The Nose, Pontoons, and Fuselage*

The nose and leading portions of the fuselage accumulate considerable ice. No suggestions have been made as to its prevention or removal. It is probable that its presence introduces some drag upon the airplane, but the chief concern probably would be with respect to the added weight.

Pontoons resemble the fuselages and the problem is quite acute. The wires and brace struts used for their support present the small size problem which is a very difficult one when clean removal of ice is required without a device which of itself creates an undesirable vibration.

(9) *Air Scoops and Edges of Other Open Channels*

Such edges accumulate ice, but if the opening is large there is risk of actual stoppage[23] only during the most extreme conditions. No suggestions for protection have been made.

(10) *Landing and Running Lights*

The running lights at the outer wing tips are often ice covered. Although no serious consequences have been observed, large mushroom shaped ice formations have been known to influence the stall characteristics of the wing. The place on the wing has occasionally been chosen too far inboard. This position has interfered with the wing De-Icer and left a wing portion outboard of the light upon which thick ice layers have accumulated. To provide adequate protection the De-Icers should extend well around the curve of the tip and, therefore, these fixtures should always be placed outside the area which should be occupied by the De-Icer.

Landing lights on the other hand, are so located that ice layers over them have a marked affect on lift and drag. It is not very serious, but because the wing De-Icers on each side keep the wing free from ice, it would appear advisable to develop a transparent removal device or to build retractable lights.

(11) *Projections upon Wing Surfaces. The Aerodynamically Smooth Airfoil.*

Ice occasionally forms upon projecting rivet heads back of the leading surfaces. The causes should be studied and the effect of such ice upon wing characteristics might well be determined. Countersunk rivets will eliminate much of this trouble and when the aerodynamically smooth wing is realized in practice this "casual" ice should not occur. However, any roughness or crack which causes even minor turbulence is a potential nucleus from which an ice formation may start. Therefore, non-wetting varnishes to fill the cracks about countersunk rivet heads should be developed.

IV. Conclusion

An airplane is a complex engineering structure with a number of parts exposed to the airstream each of which may acquire ice during flight under certain atmospheric conditions. This paper has attempted to list the most important physical conditions of atmospheric ice in relation to airplanes, and by a separate examination of the several parts upon which ice is known to form to state briefly, and rather categorically, the engineering principles which should be considered if they are to be protected.

One further point of view should have a high place in the minds of designers and investigators. Among the requirements for ice removal methods is the one that no unusual demand should be made upon the time and attention of the pilot. He faces these possibilities: during the ice season an airplane (1) must be grounded throughout the predicted duration of an ice storm, (2) the weather observations must be complete and forecasts accurate to make possible the avoidance of the ice area, or (3) the airplane must be equipped with protection devices as an insurance against the hazard of unavoidable or unpredictable ice.

But pilots cannot know the minute and second of their entry into an ice area or foresee its concentration, even though weather observations and forecasts are of the best, for air masses are in motion and conditions change between observations. Therefore, if an airplane is to fly at all over a route along which ice may be encountered, the protection equipment must be capable of action as quickly as desired by the pilot.

Some may contend that no scheme of protection can satisfy the requirements as stated in this paper. Nevertheless, because of the combination of conservative operation, by which airplanes have been grounded when conditions were bad, the skill of the pilots, and the use of proved equipment on propellers and wings, it is a fact that the ice hazard has been reduced during recent years. Many problems remain, but if thorough investigations are carried on still further progress can be made toward the goal of safety under all ice conditions.

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Analysis of Circular Rings for Monocoque Fuselages

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ABSTRACT

The distribution of reactions to loads transmitted by rings to skin in a monocoque fuselage is discussed. Formulas are derived for the moment, shear, and axial stress at all points in circular rings which are subjected to a moment, a radial force, or a tangential force applied at one point on the circumference. Curves are given for each case and their use in obtaining the stresses in the ring under any loading by superposition of separate effects is illustrated by an example.

THE SKIN REACTIONS

FORCES transverse to the longitudinal axis of a monocoque fuselage are transmitted to the skin through transverse rings. The forces thus transmitted act as shearing forces on a cross-section of the fuselage. While wrinkling of the skin may cause the distribution of this shearing stress to vary somewhat depending upon the manner of occurrence of the wrinkling, the problem becomes unduly complex if this is taken into account. It will be assumed that the skin behaves as a section not subjected to wrinkling or in which the wrinkling does not appreciably affect the distribution of skin reactions on the ring. If the skin is assumed to be very thin in comparison to its diameter, the skin reactions must be entirely tangential forces as shown in Fig. 1.

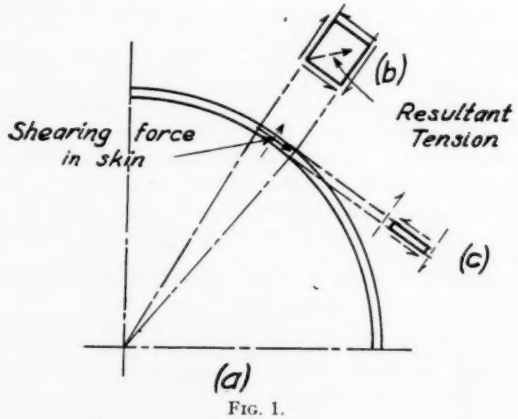

FIG. 1.

These shearing forces in a transverse plane are held in equilibrium by conjugate shearing forces in longitudinal radial planes (Fig. 1b). There can be no shearing forces at a free surface hence no shearing forces normal to the skin surface can occur in the transverse section. (This can be seen from Fig. 1c which shows by means of dotted arrows how such shearing forces would be unable to exist.) Even if the skin should wrinkle, the resultant tension would still furnish a component tangential to the skin surface (Fig. 1b) unless a very large longitudinal deflection of the fuselage occurs. Since such deflections should be very small in the usual fuselage, it may be assumed that no radial forces will be applied by the skin to the ring, or at least that such radial forces are negligible compared to the tangential forces.

A couple or moment applied to the ring will then have skin reactions distributed uniformly around the circumference, as shown in Fig. 2. The intensity of

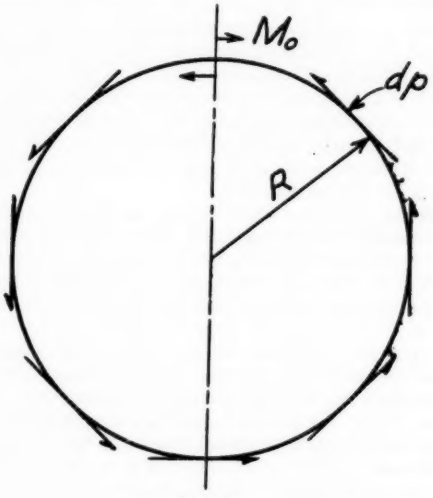

FIG. 2.

these skin reactions, per unit of length of circumference, will then be

$$dp = M_0/2\pi R^2 \qquad (1)$$

A radial force will have skin reactions as shown in Fig. 3, assuming that the common theory of flexure is valid for this case.

P is the radial force applied to the ring.
F is the transverse force transmitted to right of ring (*i.e.*, total shear).
f is unit fiber stress in skin, at plane defined by angle φ.
C_1 and C_2 are total compressive forces beyond plane defined by angle θ.
S_H is horizontal shear on two longitudinal radial planes through skin.

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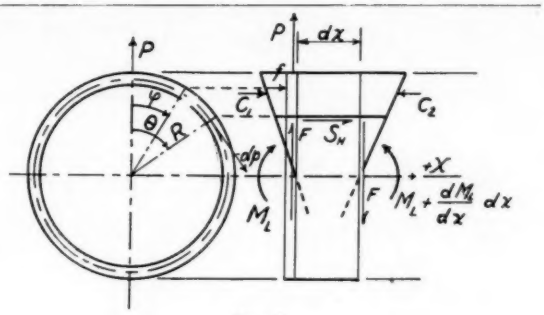

FIG. 3.

v is intensity of horizontal or conjugate tangential shearing stresses.

M_L is longitudinal moment.

Then

$$f = \frac{M_L R \cos \varphi}{\pi t R^3} = \frac{M_L \cos \varphi}{\pi t R^2} \tag{2}$$

since $I = \pi t R^3$ for transverse section of fuselage

$$C_1 = \int_{-\theta}^{+\theta} f t R d\varphi = \int_{-\theta}^{+\theta} \frac{M_L \cos \varphi}{\pi R} d\varphi$$

$$C_1 = (2 \sin \theta / \pi R)\, M_L \tag{3}$$

Similarly

$$C_2 = \frac{2 \sin \theta}{\pi R}\left(M_L + \frac{dM_L}{dx} dx\right) \tag{4}$$

And

$$S_H = C_2 - C_1 = \frac{2 \sin \theta}{\pi R} \frac{dM_L}{dx} dx \tag{5}$$

$$v = \frac{C_2 - C_1}{2t dx} = \frac{\sin \theta}{\pi t R} F \tag{6}$$

This shearing stress, v, is also the intensity of shearing stress acting tangentially in a transverse plane. Therefore the skin reaction per unit of length of circumference will be,

$$dp = vt = (\sin \theta / \pi R)\, P \tag{7}$$

In Eq. (7) the force F was replaced by P, thus giving the total skin reaction from both sides of the ring. This result[1,2,3,6] is in agreement with previously published analyses except one.[4]

STRESSES IN RING

Case I. Moment Applied at One Point (Fig. 4)

The following convention of signs will be used.

External moment, clockwise is positive.

External radial force, outward from center is positive.

External tangential force, if tending to rotate ring clockwise is positive.

Internal bending moment, positive if it produces tension on inside of ring.

Internal axial force, positive if tension.

Internal shearing force, positive if pair of opposite shearing forces form a clockwise couple.

If the ring is imagined to be cut an infinitesimal distance to right of M_0, the three redundant internal forces will be X_a (axial), X_b (shear), and X_c (moment). Using the method of consistent deflections,[5] the moment in basic statically determinate structure is,

$$M' = \int_0^\theta -\frac{M_0}{2\pi R^2} \cdot R d\varphi \cdot R\,[1 - \cos(\theta - \varphi)]$$

$$M' = -(M_0/2\pi)\,(\theta - \sin \theta) \tag{8}$$

The moments due to unit forces applied in the same sense as the redundants, are

$$m_a = -R\,(1 - \cos \theta)$$
$$m_b = +R \sin \theta$$
$$m_c = +1$$

$$EI\,\delta_a' = \int_0^{2\pi} \frac{M_0}{2\pi}(\theta - \sin \theta) \cdot R \cdot (1 - \cos \theta) \cdot R d\theta$$

$$EI\,\delta_a' = +\pi M_0 R^2 \tag{9}$$

Similarly

$$\left.\begin{aligned} EI\,\delta_b' &= +\frac{3M_0R^2}{2} \\ EI\,\delta_c' &= -\pi M_0 R \\ EI\,\delta_{aa} &= +3\pi R^3 \\ EI\,\delta_{ab} &= 0 \\ EI\,\delta_{ac} &= -2\pi R^2 \\ EI\,\delta_{bb} &= +\pi R^3 \\ EI\,\delta_{bc} &= 0 \\ EI\,\delta_{cc} &= +2\pi R \end{aligned}\right\} \tag{10}$$

Substituting these values in the equations of consistent deflection,

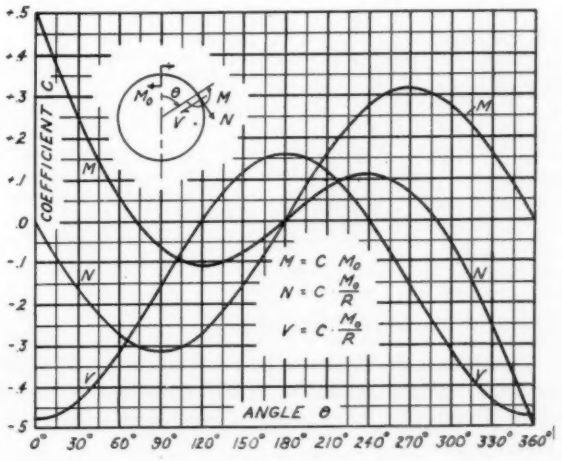

FIG. 4.

$$\left.\begin{aligned} &+ \pi M_0 R^3 + 3\pi R^2 X_a - 2\pi R^2 X_c = 0 \\ &+ 3M_0 R^2/2 + \pi R^3 X_b = 0 \\ &- M_0 R - 2\pi R^2 X_a + 2\pi R X_c = 0 \end{aligned}\right\} \quad (11)$$

Solving these simultaneously,

$$\left.\begin{aligned} X_a &= 0 \\ X_b &= -3M_0/2\pi R \\ X_c &= +M_0/2 \end{aligned}\right\} \quad (12)$$

Then

$$\left.\begin{aligned} M &= -\frac{M_0}{2\pi}(\theta - \sin\theta) - \frac{3M_0}{2\pi R} \cdot R\sin\theta + \frac{M_0}{2} \\ M &= \frac{M_0}{2\pi}[(\pi - \theta) - 2\sin\theta] \end{aligned}\right\} \quad (13)$$

Likewise

$$N = -(M_0/\pi R) \cdot \sin\theta \quad (14)$$

And

$$V = (M_0/2\pi R)(1 + 2\cos\theta) \quad (15)$$

Case II. Radial Force (Fig. 5)

By a similar analysis

$$\left.\begin{aligned} M &= \frac{PR}{2\pi}\left[(\pi - \theta)\sin\theta - \frac{\cos\theta}{2} - 1\right] \\ N &= \frac{P}{2\pi}\left[\frac{3}{2}\cos\theta + (\pi - \theta)\sin\theta\right] \\ V &= \frac{P}{2\pi}\left[(\pi - \theta)\cos\theta - \frac{\sin\theta}{2}\right] \end{aligned}\right\} \quad (16)$$

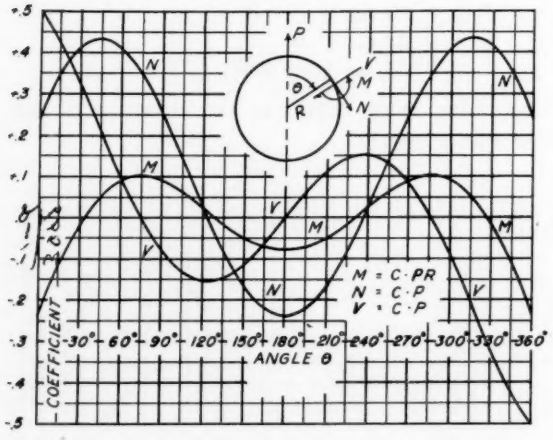

FIG. 5.

Case III. Tangential Force (Fig. 6)

In this case the skin reactions can be obtained by the principle of superposition, using those for a radial force P (applied horizontally), combined with those for a moment $P \cdot R$.

Then

$$d\dot{p} = \frac{P}{\pi R}\cos\varphi + \frac{P \cdot P}{2\pi R^2} = \frac{P}{\pi R}\left(\frac{1}{2} + \cos\varphi\right) \quad (17)$$

Repeating the previous method of analysis in this case,

$$\left.\begin{aligned} M &= \frac{PR}{2\pi}\left[(\pi - \theta)(1 - \cos\theta) - \frac{3}{2}\sin\theta\right] \\ N &= \frac{P}{2\pi}\left[\frac{\sin\theta}{2} - (\pi - \theta)\cos\theta\right] \\ V &= \frac{P}{2\pi}\left[(\pi - \theta)\sin - 1 - \frac{\cos\theta}{2}\right] \end{aligned}\right\} \quad (18)$$

Curves for the values of Eqs. (13) to (18) are shown in Figs. 4, 5, and 6. In addition to the conventions of signs previously stated, it must be observed that angles are always to be measured in a clockwise direction *from* the point at which the external force is applied *to* the point at which the stresses are to be obtained. Every external force applied to the ring can be resolved into three components corresponding to the above three cases.

For several loads, the principle of superposition is used.

Stresses at Point A

The angle, P_1 to A is 240°; that from P_2 to A is 120°.

From Fig. 4 the moment at A due to $M_0 = -15{,}588$ in. lbs at C, is -1699 in. lbs., and, due to $M_0 = +15{,}588$ in. lbs. at D, it is -1699 in. lbs. From Fig. 5 the moment at A due to radial components at C and D are from Fig. 6, each -1873 in. lbs., and the moment at A due to tangential components at C and D are $+5618$ in. lbs. each. Thus, the total moment at A is $+4092$ in. lbs.

Similarly, the axial force at A, due to

Moment at C	=	− 172 lbs.
Moment at D	=	− 172 lbs.
Radial force at D	=	− 75 lbs.
Radial force at C	=	− 75 lbs.

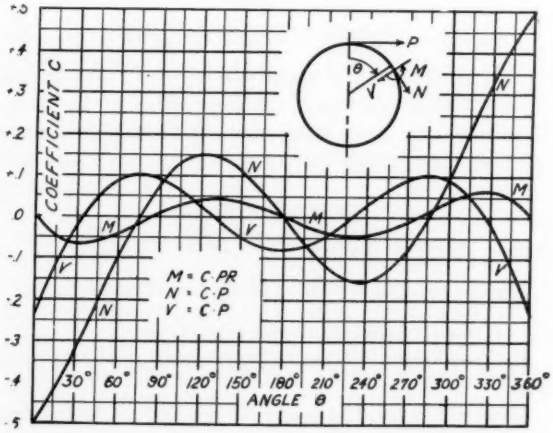

FIG. 6.

Tan. force at C	=	+ 791 lbs.
Tan. force at D	=	+ 791 lbs.
Total axial force		+1088 lbs.

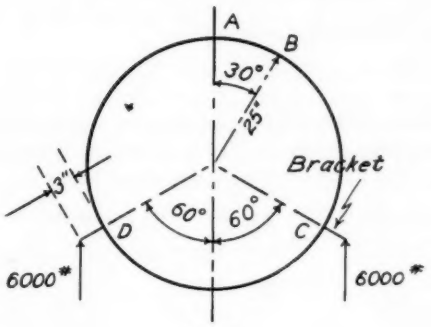

FIG. 7.

EXAMPLE

P_1 Lbs.	P_2 Lbs.	Tangential Component Lbs.	Radial Component Lbs.	Moment In. Lbs.
6000		−5196	−3000	−15,588
	6000	+5196	−3000	+15,588

The shearing force at A, due to

Moment at C	=	0
Moment at D	=	0
Rad. force at C	=	+ 457 lbs.
Rad. force at D	=	− 457 lbs.
Tan. force at C	=	+ 130 lbs.
Tan. force at D	=	− 130 lbs.
Total shear	=	0

Repeating this for points at intervals of 30° around the semi-circumference, one can obtain sufficient data to plot curves of moment, axial force, and shear.

CONCLUSION

The procedure used in this paper is particularly advantageous for use in computations, because it is possible to obtain the stresses at any point of the stiffener ring directly from the diagrams, without determining the skin reactions. In other treatments of the subject,[2,3,6] the stresses at one point of the ring are obtained, and the stresses at other points must be computed, using these stresses and the given forces and their skin reactions. The results given by Newell[6] could be used to determine the stresses at all points, if the angle α assumes different values, but then it would be necessary to resolve the external forces into different radial and tangential components for each different angle α.

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[3] Ruffner, Benjamin F., Jr., *Monocoque Fuselage Circular Ring Analysis*, Journal of the Aeronautical Sciences, Vol. 6, No. 3, page 114, January, 1939.

[4] Younger, J. E., *Structural Design of Metal Airplanes*, McGraw-Hill, 1935, page 226.

[5] Parcel and Maney, *Statically Indeterminate Stresses*, Second Edition, John Wiley and Sons, 1936, page 112.

[6] Newell, Joseph S. *The Use of Symmetric and Antisymmetric Loadings*, Journal of the Aeronautical Sciences, Vol. 6, No. 6, pages 235–239, April, 1939.

Letters to the Editor

August 17, 1939

Dear Sir:

The experiments cited by Sears and Kuethe in their recent article "The Growth of Circulation of an Airfoil During Flight Through a Gust" (July, 1939, issue of the Journal) cannot be considered a valid test of the unsteady lift theory. The steady value of the circulation measured in these experiments is in marked disagreement with wind-tunnel values—and hence also with the accepted airfoil theory for steady motion.

The appearance of agreement between the two-dimensional theory and the tests is the result of dividing out the absolute magnitudes and is without significance. The airfoil theory does not predict the circulation in percentage—but as a definite value determined by the Kutta hypothesis.

ROBERT T. JONES
National Advisory Committee for Aeronautics

August 20, 1939

Dear Sir:

Reference is made to Robert T. Jones's Letter to the Editor of August 17.

The measurements of the circulation of a wing passing through a gust were not as accurate as the measurements of steady forces in wind tunnels; the complexity of the problem and the difficulties of measurement precluded this. In my original report on these measurements the maximum error was estimated as within 8 to 10 percent of the maximum circulation. The poor agreement of the measured circulation at 0° angle of attack with that predicted on the basis of wind-tunnel tests was pointed out and the possible error mentioned above substantially accounts for this discrepancy. While I doubt if this degree of error obtains for the increment of the circulation due to the gust, the possibility that errors in the measurements might cause the measured circulation to be less than the actual and that this circumstance would decrease the gap between the measurements and the Jones theory were pointed out in the Sears-Kuethe paper.

The comparison with theory on the basis of dividing out the absolute magnitudes is significant to the extent that the results are accurate, since the absolute magnitude used to render the values dimensionless is based on airfoil theory, rather than on the measurements themselves.

A. M. KUETHE

Autosyn Application for Remote Indication of Aircraft Instruments

W. A. REICHEL AND R. C. SYLVANDER

Pioneer Instrument Division, Bendix Aviation Corporation

ABSTRACT

Various systems of remote indication as applied to aircraft are briefly discussed and a description of the "Autosyn" system as developed by the Pioneer Instrument Company is given. The various characteristics of an Autosyn motor are presented from an instrument design and operation standpoint. The range of their application as remote indicating instruments is indicated.

INTRODUCTION

AS THE size of commercial and military airplanes increased, the need for a reliable and accurate method of remote indication of such functions as fuel pressure, engine speed, fuel flow, and wheel and control surface positions became important. Usual methods, such as running fuel and oil lines to gages on the instrument board and flexible shafts to mechanical tachometers, became unsafe or impractical due to the increased distances from the engine to the cockpit. Also, with the use of multiple engines and consequent multiplicity of instruments, the importance of utilizing instrument board space to the best advantage became imperative.

In 1932, the Autosyn was applied to the remote indication of aircraft instruments and an experimental installation made on an airplane. In 1934, the first application on production airplanes was made. During the last year, its use as an indicator of certain functions has become standard on certain larger commercial and military planes, and on some smaller planes where conservation of instrument-board space is of prime importance.

DESCRIPTION OF THE SYSTEM AND MOTOR

The Autosyn system for remote indication is an electrical system, chosen after extensive experimentation with many other methods because of its reliability, accuracy, and adaptability under all operation conditions. The Autosyn is a small self-synchronous motor. It is similar to the self-synchronous motors used since 1920 by the U. S. Navy in its order signal systems and in many industrial applications. The Autosyn system comprises one Autosyn transmitter in which the rotor is moved by some mechanical means, just as the pointer of a pressure gage is moved by the bourdon tube, electrically wired to one or more exactly similar Autosyns having a pointer on its rotor and equipped with a dial.

The principle of the Autosyn motor being well known and the use of the self-synchronous system extensive, there is no need to go into its detailed construction. A simple wiring diagram, Fig. 1, shows the essential features of the Autosyn system described below.

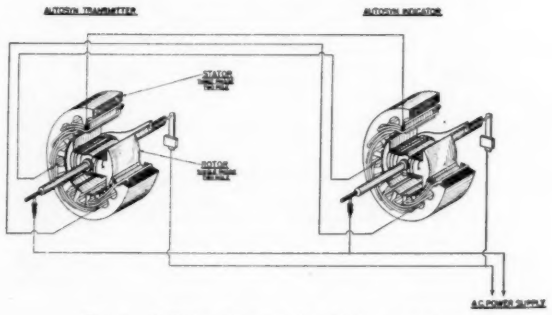

Fig. 1. Wiring diagram for Autosyn system.

The Autosyn transmitter and receiver (or indicator) have three-phase, two-pole stators and single-phase, two-pole rotors. Alternating current is applied to both rotors, and the stator leads of one Autosyn are connected to the corresponding stator leads on the other. Each Autosyn is essentially a variable transformer. A definite set of voltages is induced across the stator leads by the rotor or primary current. For any position of the rotor, there are three voltages at the stator leads that are reproduced whenever the rotor assumes that position. Due to the choice of a three-phase secondary and two-pole rotor and stator, there is only one position at which any particular combination of voltages is reproduced. Hence, when current is applied to the rotor a distinct set of three voltages is produced at the leads of each stator. If both rotors happen to be in the same relative position, both sets of stator voltages are equal and opposite and no current can flow in the stator leads. Hence, no torque is produced. If, however, the rotors are not in the same relative position, the sets of stator voltages will not be equal and current will flow in the stators, causing relative rotation of the rotors. As soon as both rotors have the same relative position, the stator voltages will be balanced and no further rotation can occur.

Hence, when one rotor is moved, the other will move with it and the entire system operates as a flexible electrical coupling.

DISCUSSION OF REMOTE INDICATING SYSTEMS

The ideal system for remote indication must satisfy many requirements. The weight of the entire system must be a minimum; the power requirements must be

Presented at the Instrument Session, Seventh Annual Meeting I. Ae. S., January 25, 1939.

low; the transmitters and indicators must be readily detachable from their connecting means; units must be interchangeable (that is, any transmitter should operate any indicator); the accuracy of the system must be unaffected by the addition of a second indicator.

It was soon apparent that of the three possible systems, namely, mechanical, hydraulic and electrical, only an electrical system could fulfill certain of these requirements, because of freedom from change of calibration due to loss of liquid from leaks or at disconnection and also high friction of mechanical means.

Direct Current Electrical Systems

Among the systems operating on direct current were those using some form of potentiometer as a transmitter and some form of voltmeter or ratio meter, as indicator, and those using a means of position comparison thermally actuated by current. Usually there were difficulties with thermal compensation at both transmitter and indicator; in many, the range of scale was too limited; in others, brushes and sliding contacts at the transmitter could not be avoided at points where gasoline vapors might be present. There was usually high friction present at the transmitter due to these same brushes, and sliding contacts prevented accurate operation under the sometimes not-too-powerful forces available in reasonably sized prime movers; some were affected by voltage variations or length of connecting leads; few allowed the addition of a second indicator without destroying accuracy altogether.

Alternating Current Systems

Possible alternating current systems are based on inductance bridges, on frequency measurement, on phase meters and on many other principles. The Autosyn system answers the requirements with respect to weight, power required, interchangeability, and operation of the second indicator. Further, it is free from change in reading such as may occur in hydraulic systems due to loss of liquid from leaks or at broken connections, and is also free from the high friction of mechanical means of remote indication. There are no errors introduced by temperature changes at transmitter and indicator, the scale range is unlimited, it is possible to avoid all sliding contacts, and the coupling or "electrical stiffness" is high compared to any extraneous torques caused by normal inaccuracies in geometric construction expected in manufacture and by impedances and couplings present in the interconnecting circuits. In addition to giving good accuracy over a wide range of operating conditions, the units can be built in a sturdy manner to give long life under conditions encountered on aircraft.

In addition, the design of a two-pointer indicator for conservation of instrument-board space and simultaneous indications on one dial of bi-motor functions is possible.

Characteristics of the Autosyn

In order to apply the Autosyn motor to instrument design, it is necessary to consider the various characteristics of the motor.

The driven rotor lags the driving rotor by an angle proportional to the torque transmitted in the Autosyn system as it does in the flexible shaft drive. In the Autosyn, this characteristic is called electrical stiffness and is measured in torque units per degree of relative displacement. The Autosyn has another characteristic, not found in the flexible shaft, which consists of a tendency to assume certain positions. This tendency, called "pull," varies throughout the range and is measured in units of torque. This pull is the result of small geometrical, electrical, and magnetic variations encountered in manufacture and must be overcome by the stiffness of the mechanical means used to drive the Autosyn system. This is easily accomplished.

Table 1 gives electrical stiffness and maximum pull data for the type 769 Autosyn.

Table 1. Power Consumption per Instrument, Type 769 Autosyn

2 watts or 5 volt amperes under rated conditions of 32 volts, 60 cycles. Weight, 10.5 ounces.

Voltage Input	Electrical Stiffness Gram Cm. per Degree	Max. Pull Gram Cm.
16	0.11	0.50
24	0.31	0.75
32 (rated)	0.63	1.35
40	1.20	2.00

The electrical stiffness and pull data are for a pair of motors. Although the data are given for a range from 16 to 40 volts, the best results are obtained between 24 and 36 volts at 60 cycles.

These motors will operate satisfactorily over a wide frequency range, best results, however, being obtained between 45 and 120 c.p.s. with the input voltage varying proportionately with the frequency. Fig. 2 shows the effect of frequency for two rates of variation of the volt-

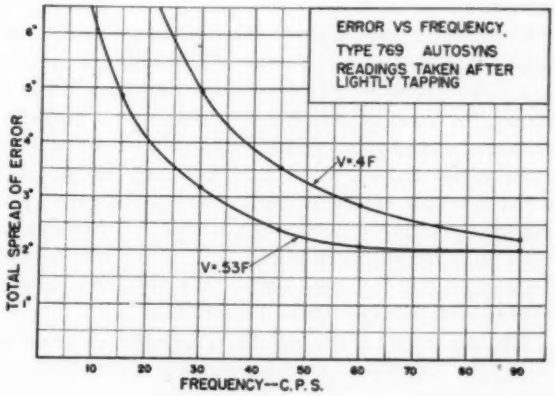

Fig. 2. Spread of error versus frequency. Type 769 Autosyn.

age, V, upon the total spread of errors for a pair of coupled 769 Autosyns. The total spread is the sum of the maximum positive and negative errors in the indicator reading, the transmitter being rigidly rotated.

Fig. 3 shows the errors over a full revolution for a pair of these motors, taken every two degrees under rated conditions of 32 volts, 60 cycles. The errors are electrical in nature, bearing friction being eliminated by a light vibration similar to that always encountered in an airplane application. The same factors that cause the pull, described above, are responsible for these errors. Regions of pull are shown by vector arrows, the pull being always directed away from unstable points toward stable points shown.

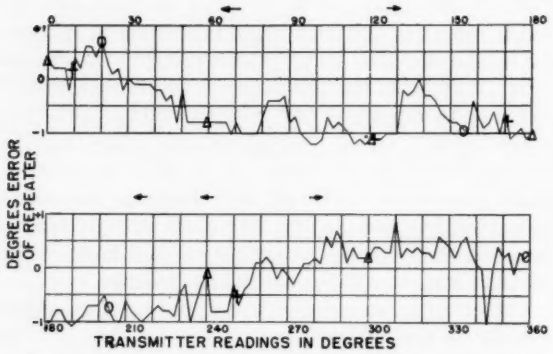

FIG. 3. Accuracy curves for 769 Autosyn. ○—stable points; + —unstable points; ← —maximum pull points; Δ—electrical zero points.

Also given are electrical zero points, showing the position taken by the indicator when two of the three interconnecting wires are short-circuited. These points form definite reference points for pointer placement, thereby making interchangeability of instruments practicable.

If a second indicator is connected in parallel to the original, the errors shown in Fig. 3 would be increased by approximately twenty-five percent. In considering these errors, attention is called to the fact that an error of one degree is less than one-third of one percent of a full dial revolution.

Continuous experimentation has been carried on with the object of still further decreasing the weight and power requirements of the Autosyn system. Fig. 5 shows, for comparison (left to right), (1) a self-synchronous motor removed from the German submarine *Deutschland* when it was interned during the war, (2) a self-synchronous motor such as is used at present in marine signalling systems, (3) the type 769 Autosyn as used in aircraft instruments, and (4) a new model Autosyn called the type 7000. The reduction in size over that of the type 769 is of importance.

Characteristics of the type 7000 Autosyn are given in Table 2. The electrical stiffness and pull data are for a pair of motors.

Fig. 6 shows the errors over a full revolution for a pair of these motors taken every two degrees under rated conditions of 52 volts, 800 cycles. The errors are of the same order of magnitude as those shown by Fig. 3 for the type 769 Autosyn.

Some Applications

Autosyn instruments have been developed for indicating the following regular functions on any aircraft: Positions of Flaps, Bomb Doors, Landing Gears, Tail

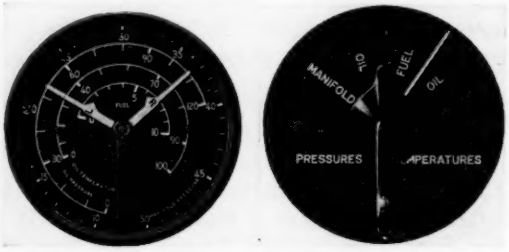

FIG. 4. Multiple scale dual indicator and selector switch.

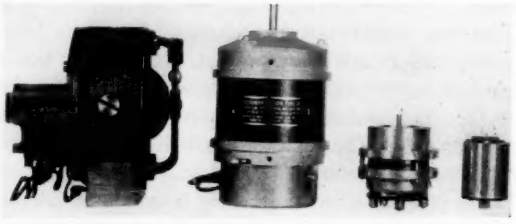

FIG. 5. The type 7000 Autosyn compared with other self-synchronous motors.

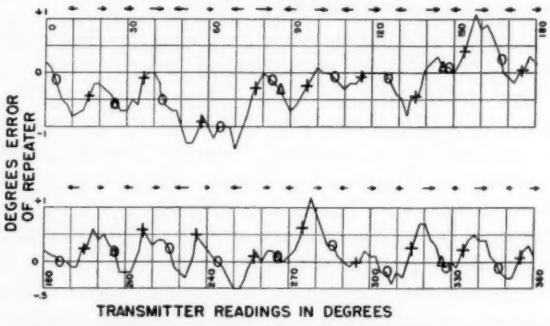

FIG. 6. Accuracy curves for type 7000 Autosyn. ○—stable points; + —unstable points; ← —maximum pull points; Δ—electrical zero points.

TABLE 2. POWER CONSUMPTION PER INSTRUMENT, TYPE 7000 AUTOSYN

1 watt or 3 volt amperes under rated conditions of 52 volts, 800 cycles; or 0.5 watt or 1.5 volt amperes for a 26 volt, 400 cycle supply. Weight, 3.5 ounces.

Voltage Input 800 Cycles	Electrical Stiffness Gram Cm. per Degree	Max. Pull Gram Cm.
28	0.03	0.06
40	0.06	0.11
55	0.13	0.21
72	0.23	0.38

Wheel; Manifold Pressure; Fuel Pressure; Oil Pressure; Oil and Coolant Temperatures; Engine Speed; Fuel Quantity; Fuel Flow.

These indicators are of the single pointer or two-pointer type. The indicators for all functions differ only in the dial markings.

Other applications have been made, such as for the indication of loop direction in radio direction finders, magnetic compass repeaters and recording instruments.

Fig. 4 shows the dial of a multiple scale dual indicator and selector switch. This dual indicator shows the manifold pressure, oil pressure, fuel pressure, and oil temperature of each of two engines. The amount of information given in a very small instrument-board space is noteworthy.

Fig. 7* shows the method of mounting transmitter units for manifold pressure, fuel pressure, oil pressure, and oil temperature in an engine nacelle of the Boeing 314 airplane. The units are connected to the engine with short lengths of hose and connecting tubing. They are mounted on a shock-absorbing panel to protect them against vibration. Connections between the transmitters and indicators are made by wires. The elimination of long lengths of hose and connecting tubing materially reduces weight and fire hazard.

Fig. 8* is the arrangement of the flight engineer's panel on the Boeing 314. This shows various functions for four engines, each function requiring two dual indicators. The functions shown are engine speed, manifold pressure, fuel flow, fuel pressure, oil pressure, oil temperature, and fuel quantity.

* Courtesy Boeing Airplane Company

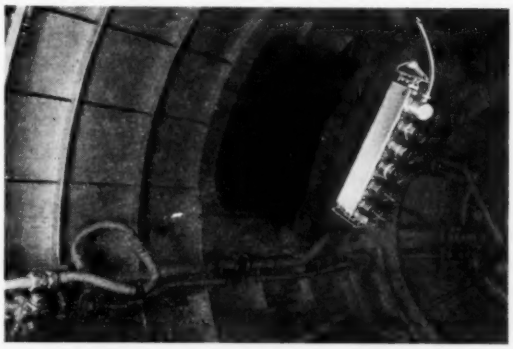

FIG. 7. Transmitter units installed in engine nacelle of Boeing 314.

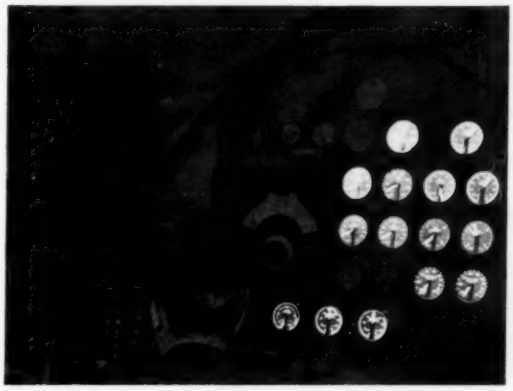

FIG. 8. Autosyn dual indicators on flight engineer's panel on Boeing 314.

Book Reviews

Schriften der Deutschen Akademie der Luftfahrtforschung, Heft 1 and Heft 2; R. Oldenbourg, München and Berlin, 1938; 43 and 47 pages, R.M. 2.70 and 2.90, respectively.

These two booklets give the proceedings of two separate meetings of the German Academy of Aeronautical Research.

Heft 1 concerns the meeting on March 1, 1938. It opens with an address by General Göring, President of the Academy. There follow two technical papers, "The Development of Flight Performance" by Willy Messerschmitt, and "The Development of the Airplane Engine" by Otto Mader. The first is a general treatment of the various performance items from the time of the first available data to the present. The factors tending to place limits on the performance are briefly discussed. The second paper treats the airplane engine along much the same lines. Problems of construction, weight, fuel injection, and cooling are briefly taken up.

Heft 2 gives the proceedings of the "Third Open Meeting" of the Academy on June 17, 1938, to commemorate the 100th anniversary of the birth of Count Zeppelin (July 8, 1838). The opening address is by General Milch, Vice-President of the Academy.

Two technical papers, "Precautions for Improving the Zeppelin-Airship for Long Range Air Transport" by Ludwig Dürr, and "The Application of the Zeppelin-Airship for Long Range Air Transport" give, in 32 pages, the strength and performance factors and flight records of the various recent German airships.

Magnesium and Its Alloys, by J. L. HAUGHTON and W. E. PRYTHERCH; Department of Scientific and Industrial Research, London; First American Edition, Chemical Publishing Company of New York, Inc., 1938; 100 pages, $1.50.

For the past six years the National Physical Laboratory has been investigating the physical, chemical, and engineering properties of magnesium and its alloys. Some of the results have been reported in the *Journal of the Institute of Metals*, but a considerable amount of hitherto unpublished material has been added to it, and the result is a compact, readable, and informative presentation of the available data.

The book discusses sources, production, and properties; melting and casting; plastic deformation; rolling, forging, extrusion, and heat treatment; mechanical properties at ordinary and elevated temperatures; and constitution of magnesium and its alloys.

Sixty figures giving various properties and an extensive bibliography make the work particularly valuable for reference purposes.

Static and Dynamic Model Similarity

FELIX NAGEL

The Glenn L. Martin Company

IN MANY cases applied air loads cause deflections in the structure of an airplane which in turn change these loads to a very large extent, especially if an unstable equilibrium condition is approached. In actual airplane design, this is primarily known as wing divergence and flutter. The analytical treatment of these cases is in general very involved and can often be carried out only with simplifying assumptions. An entirely different method of approach is to build an elastically similar model and test it in the wind tunnel. In the following, a brief summary of the similarity laws which govern these conditions is given.

The following symbols are used:

		Dimension
a	= chord length (Fig. 1)	length
A	= cross-section area	length^2
A_e	= enclosed area for torsion (Fig. 1)	length^2
b	= span of wing	length
C	= circumferental length for torsion	length
E	= modulus of elasticity for normal stresses	force/length^2
F	= subscript for full scale	0
g	= earth acceleration	length/time^2
G	= modulus of elasticity for shear stresses	force/length^2
I	= moment of inertia of cross-section area	length^4
k	= reduced frequency (Eq. (6))	0
L	= length of vibrating wing	length
M	= subscript for model scale	0
o	= subscript for root section of wing	0
P	= force	force
Q	= torque moment	force·length
r	= radius of gyration	length
s	= thickness of sheet (Fig. 1)	length
v	= flutter speed	length/time
v_D	= divergence speed	length/time
w	= loading from weight distribution	force/length
W	= weight	force
y	= movement in vertical direction (Fig. 1)	length
α	= angle of twist (Fig. 1)	0
γ	= density of material	force/length^3
ζ	= frequency coefficient	0
κ	= force ratio	0
λ	= length ratio	0
μ	= mass ratio (Eq. (3))	
ρ	= air density	$\frac{\text{force·time}^2}{\text{length}^4}$
τ	= time ratio	0
ω	= frequency	1/time
$\sim$	= sign for proportionality	

For geometric similarity throughout, length, force, and time ratios λ, κ, and τ, respectively, are connected by Newton's equation

$$\kappa = \frac{\gamma_F}{\gamma_M}\frac{\lambda^4}{\tau^2} \tag{1}$$

The speed ratio is $v_F/v_M = \lambda/\tau$ (2)

The dimensionless parameters governing flutter are reduced frequency k, mass ratio μ, and location of elastic, gravity and hinge axes and mass radii of gyration expressed as percentages of the chord length. These parameters are the coefficients of the differential equations describing flutter as outlined by Theodorsen[1] and others. For similarity they must have the same value for full size and model. This condition can easily be satisfied for the above-mentioned percentages of chord length. The problem thus reduces to obtaining equal values of k and μ. Since

$$\mu = \frac{w/g}{a^2\pi\rho/4} \tag{3}$$

$$w_F/w_M = \lambda^2\rho_F/\rho_M = (A\gamma)_F/(A\gamma)_M = (\gamma Cs)_F/(\gamma Cs)_M \tag{4}$$

or $$W_F/W_M = \lambda^3\rho_F/\rho_M \tag{5}$$

which governs the individual weights in pounds of the model. Likewise

$$k = \frac{1}{2}\frac{\omega a}{v} \tag{6}$$

Whence, using Eq. 2,

$$\frac{\omega_F}{\omega_M} = \frac{a_M}{a_F}\frac{v_F}{v_M} = \frac{1}{\lambda}\frac{v_F}{v_M} = \frac{1}{\tau} \tag{7}$$

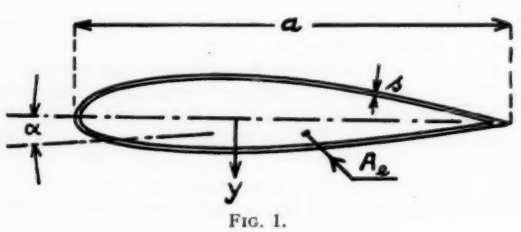

FIG. 1.

Received March 27, 1939.

To satisfy the frequency condition (Eq. (7)), it must be remembered that the bending frequency is given by

$$\omega_y^2 = \zeta_y \frac{E_0 I_0 g}{L^4 w_0} \tag{8}$$

If torsion is taken by a hollow shell,

$$\omega_\alpha^2 = 4\zeta_\alpha \frac{G_0 A_{e_0}^2 s_0 g}{C_0 L^2 w_0 r_0^2} \tag{9}$$

For constant cross-section of wing fixed at one end,

$\zeta_y = 1.875^4 = 12.36$; $\zeta_\alpha = \pi^2/4$. Since

$$L_F/L_M = r_F/r_M = \lambda \tag{10}$$

one obtains, by substituting Eqs. (8) and (9) in Eqs. (4) and (7),

$$\frac{(EI/\rho)_F}{(EI/\rho)_M} = \frac{(GA_e^2 s/C\rho)_F}{(GA_e^2 s/C\rho)_M} = \frac{\lambda^6}{\tau^2} = \left(\frac{v_F}{v_M}\right)^2 \lambda^4 \tag{11}$$

Using the value ρ_F/ρ_M from Eq. (4),

$$\frac{(EI/A\gamma)_F}{(EI/A\gamma)_M} = \frac{(GA_e^2/C^2\gamma)_F}{(GA_e^2/C^2\gamma)_M} = \left(\frac{v_F}{v_M}\right)^2 \lambda^2 \tag{12}$$

where I/A is the square of the radius of gyration of the cross-sectional area of the spar, and A_e/C is proportional to the height of the wing section. Making the additional assumptions

$$(I/A)_F/(I/A)_M = (A_e^2/C^2)_F/(A_e^2/C^2)_M = \lambda^2 \tag{13}$$

one obtains

$$\frac{(E/\gamma)_F}{(E/\gamma)_M} = \frac{(G/\gamma)_F}{(G/\gamma)_M} = \left(\frac{v_F}{v_M}\right)^2 \tag{14}$$

This equation is known as Cauchy's law. It is usually derived by substituting in Eq. (1), Hook's law for equal strain of full size and model

$$\kappa = \frac{E_F}{E_M}\frac{A_F}{A_M} = \frac{E_F}{E_M}\lambda^2$$

Therefore, for equal values of μ Eq. (4) or (5) must be satisfied, and for equal values k Eq. (11) or (12), but not necessarily (14), must be satisfied. This last equation was derived from Eq. (12) with the additional assumption of Eq. (13), not required for flutter similarity. Assuming, however, that values from Eq. (13) will be approximated in an actual flutter model, the following conclusions can be drawn from Eq. (14):

The ratio of flutter speed in the tunnel to that in full flight depends only on the materials used for full scale and model. If they are the same, both speeds also become the same, which is an unfortunate situation, since in most cases the flutter speed of a full-size modern airplane cannot be attained in the tunnel. To avoid this, $(E/\gamma)_M$ must be made smaller than $(E/\gamma)_F$ by using plastics like those made from cellulose acetates and nitrates.

If quite arbitrarily the additional postulate is made, that all cross-sectional areas are scaled as λ^2, *e.g.*,

$$A_F/A_M = (Cs)_F/(Cs)_M = \lambda^2 \tag{15}$$

it follows from Eq. (4) that

$$\rho_F/\rho_M = \gamma_F/\gamma_M \tag{16}$$

This equation is equivalent to Kaufmann's Eq. (12) as given in reference 2. For equal air densities in full flight and tunnel both would therefore have to be built from the same material, which in turn would require that the flutter speed for full scale has to be reached in the tunnel, as was mentioned above. Great emphasis must be laid on the fact that to obtain equal values of μ Eq. (4), but not Eq. (15), is necessary. In other words, geometric similarity throughout is not required. This is also of great practical help, since it is almost impossible to scale thin gages such as outside skin covering down according to the length scale λ, and, in addition, results can be obtained with wind-tunnel air speeds far below the actual flutter speed of the full-scale airplane. From the preceding formulas the ratios of bending and torsional stiffness of full size and model can be calculated as follows:

Since

$$\omega^2 \sim \frac{dP/dy}{W} \sim \frac{dQ/d\alpha}{Wr^2}$$

one obtains, using Eqs. (5) and (7),

$$\frac{(dP/dy)_F}{(dP/dy)_M} = \lambda\left(\frac{v_F}{v_M}\right)^2 = \frac{\lambda^3}{\tau^2} \tag{17}$$

$$\frac{(dQ/d\alpha)_F}{(dQ/d\alpha)_M} = \lambda^3\left(\frac{v_F}{v_M}\right)^2 = \frac{\lambda^5}{\tau^2} \tag{18}$$

Eqs. (17) and (18) furnish a check for Eq. (11) and can also be applied to determine elastic properties of supports for various masses, like engines. The value $dQ/d\alpha$ from Eq. (18) can further be used to evaluate the speed ratio for wing divergence speed,

$$v_D \sim \sqrt{\frac{dQ/d\alpha}{\rho b a^2}} \tag{19}$$

assuming the same elastic axis location of full size and model. For geometrically similar planforms of the wing,

$$(ba^2)_F/(ba^2)_M = \lambda^3 \tag{20}$$

It follows immediately from Eqs. (18), (19), and (20);

$$(v_D)_F/(v_D)_M = v_F/v_M \tag{21}$$

or the divergence speed ratio is the same as the flutter speed ratio, as could have been expected.

Reference

[1] Theodorsen, Theodore, *General Theory of Aerodynamic Instability and the Mechanism of Flutter;* N.A.C.A. Technical Report No. 496, 1934.

[2] Kaufmann, W., *Über die Ähnlichkeitsbedingungen für Flatterschwingungen von Tragflügeln; Luftfahrtforschung,* Bd. 16, No. 1, pages 21-26, January, 1939.

Additional Help in Beam-Leg Identification

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IN RANGE flying, a pilot in the immediate vicinity of his destination is absolutely dependent upon receiving his particular range and identifying the leg of that range.

In abnormal weather, when static prevails and a high wind of unknown velocity may be encountered, the identification of the particular leg of a beam becomes a problem of serious importance. During the past year there have been at least two failures of the pilot to identify the leg which he had intersected.

In identifying the particular leg of a beam the pilot has three factors with which to work; first, the sequence of signals encountered during his 90° turn; second, the compass heading while following the leg; third, the change in volume as the leg is followed.

The presence of an unknown wind approaching half airspeed of the airplane may change these factors to a negative factor, a null-factor, and a positive factor, respectively.

A few instances have come to the attention of the author, in which the pilot had considerable difficulty in identifying the leg, due to a strong cross-wind.

Two quadrants of the Oakland, California, range have an angle of 120°. There are 44 ranges having still broader quadrants. On such ranges a wind of half airspeed can rob the pilot of the possibility of determining uniquely, by geometrical turning and by compass heading, which leg has been intersected.

Double Compass Method

Under exceptional conditions the pilot may be in doubt which leg has been intersected. He may determine this by the following method. Follow the leg long enough to obtain a compass heading. Turn around and follow it in the opposite direction and obtain the new compass heading. The median of the two headings is at right angles to the leg. Add 90° and the result will be the leg heading, independent of the wind.

In Fig. 1, the vectors S and S' represent the two compass headings. W is the unknown wind. The median of S-S' is at right angles to the leg.

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Fig. 2 shows the Link Trainer track made by the author when placed on an unknown range with an unknown high wind and obliged to measure the angle of the leg in order to identify it. The compass headings obtained were 265° and 65°. These measured the leg angle as 255°. This is sufficiently close for identification.

It is worth pointing out that the high-wind-flat-quadrant difficulty is greater as the flatness of a quadrant increases. Also, it is greater for slower speed airplanes.

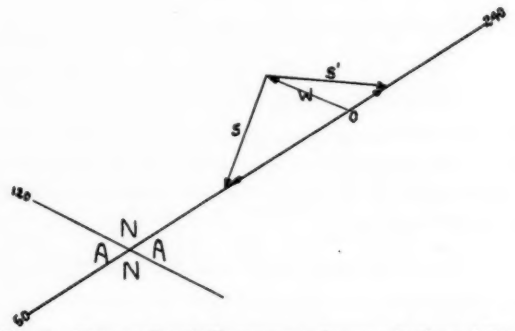

FIG. 1. Vectors S and S' represent the magnitude and direction of airspeed of an airplane at O in order for it to follow the beam in each of the two directions, in the presence of a wind W. The bisector of $S - S'$ is at right angles to the beam, independent of the wind.

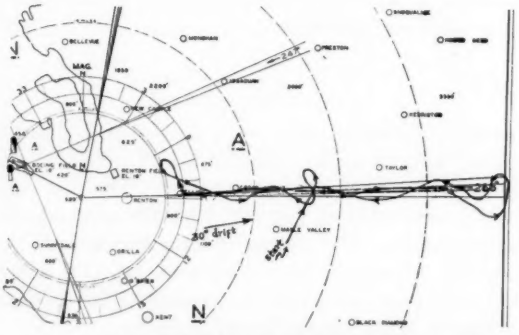

FIG. 2. Link Trainer track made by a pilot encountering an unknown range in an unknown high wind; flying both directions in order to measure the heading of the leg. Resulting determination, 255°; tabular value, 268°.

Book Reviews

Aircraft Design, Vol. I, Aerodynamics, by C. H. Latimer Needham; Chapman and Hall Ltd., London, 1939; 215 pages, 13s. 6d.

This book is the first of two volumes dealing with the general principles of aircraft design and outlines in simple language, the fundamentals of flight, and general performance. The second volume will deal mainly with the mathematical treatment of design.

The first chapter reviews the general properties of air and the nature of fluid resistance. It then discusses scale effect and

Reynolds Number particularly in regard to applications in the wind tunnel, and concludes with a short survey of the various types of wind tunnels and techniques.

Chapters II and III present clearly the nature of the flow past bodies of various types and the methods by which such flow may be visualized. Suitable sketches greatly facilitate an understanding of the dependence of resistance upon the shape of the body and its wake characteristics. The evolution of the airfoil from the flat plate is briefly touched upon. The author then treats the fundamental principles of the mechanics of lift and, after introducing the concept of circulation, proceeds to discuss the nature of airfoil pressure distribution and of center of pressure travel.

The properties of airfoils and the effects of airfoil shape variations upon the aerodynamic characteristics are dealt with in the next two chapters. The text employs the system of aerodynamic coefficients in use in this country. The use of these coefficients is suitably illustrated with curves and numerical examples. Some space is devoted to discussions of downwash, induced drag, and the effect of aspect ratio. The treatment of the effects of airfoil shape variation is viewed, naturally, from the standpoint of the designer.

The arrangement of the lifting surface particularly in regard to planform provides the subject matter for Chapter VI. The author treats the effects of wing taper, tip shape, twist, and other variations in design on airplane performance. Considerable space is devoted to biplane interference, gap, and stagger, which is followed by a brief mention of the several other types of heavier-than-air craft.

The following two chapters deal with steady flight and flight stability. Suitable diagrams illustrate the nature of the expected forces at various flight attitudes. While no mathematical treatment of stability is introduced, a clear picture is presented, nevertheless, of the various airplane movements and the effects of the tail surfaces and of sweep-back and dihedral.

Chapters IX and X are devoted to discussions of the control system and of various high-lift devices. Considerable attention is directed toward the operating system for the controls and toward the several methods of obtaining control balance. The slotted wing is analyzed in some detail while all of the accepted types of variable-camber and variable-area flaps are summarized and compared. Some quantitative figures are given.

After a short chapter dealing with the dynamic loads experienced by the airplane during various maneuvers, there follows a treatment of general propeller performance whereby the relations of the propeller to the engine and to the airplane as a whole are discussed. The blade element theory is presented. Characteristics of variable-pitch propellers, effect of altitude, and interference effects are a few of the main topics touched upon.

In Chapter XIII are developed the fundamental equations for the calculation of airplane performance with some numerical examples included. A concise discussion of the effects of wing, power, and span loading follows.

The final chapter deals with parasite drag and interference drag. Emphasis in the former case is placed upon surface roughness, fuselage shape, and the relation between engine cooling and cowling resistance. Clean design is stressed throughout the discussions. Only a small amount of numerical data on parasite drag are given.

The book accomplishes commendably the objective which it proposes to attain, as set forth in the preface, that is: to present the fundamentals of flight mechanics sufficiently that a minimum of explanations will be necessary in the second volume, dealing with the mathematical treatment of airplane design, for an understanding of the principles underlying the various design features. The text makes no pretense of being other than fundamental. It is written in a clear and concise manner and its statements are to the point. Consequently, it is not laborious to digest. As a text it should serve as an introduction to aerodynamics, stability, and design, although, for this purpose, the lack of problem lists is to be regretted. For engineers who wish to cover the necessary fundamentals prerequisite to a study of design and as a source of references to more original and advanced work, it is recommended.

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Theoretical Hydrodynamics, by L. M. Milne-Thomson; Macmillan and Company, Ltd., New York and London, 1938; 552 pages, $11.25.

This book is designed primarily as a textbook on the theory of classical hydrodynamics. The treatment of the subject is clear and concise and covers essentially the scope of Lamb's *Hydrodynamics* or Ramsey's *Hydrodynamics*. It differs in its treatment compared to these books principally in the consistent use of vector analysis. This is no doubt a highly desirable step; it is, however, to be regretted that the author did not adopt the standard Gibbs notation. Instead, the author uses for the scalar product between two vectors $\mathbf{ab}$, for the vector product $\mathbf{a}_\wedge\mathbf{b}$, for the gradient $\nabla\phi$, for the divergence $\nabla\mathbf{F}$, for the rotation $\nabla_\wedge\mathbf{F}$. The book contains a brief introduction to some of the more advanced mathematical methods used in the book, such as vector analysis and complex variables. With the aid of these chapters the engineering student familiar with advanced calculus should be able to follow the treatment given in the book.

The viewpoint from which the book is written is, however, principally that of the mathematician. The author obviously enjoys the application of the elegant classical mathematics such as conformal transformation, more for the sake of the mathematics than for its practical usefulness. Thus these subjects occupy perhaps an unduly large proportion of the book to the exclusion of topics less elegant mathematically, such as the theory of lubrication, boundary layers, and turbulence. On the other hand this is not necessarily a disadvantage of the book, for it permits a fuller treatment of some of the complicated. mathematical subjects. Also many of the omitted topics have recently been discussed much more completely than would be possible here in the two volumes on *Modern Developments in Fluid Dynamics* by S. Goldstein and the Aeronautical Research Committee.

The book starts in Chapter I with Bernoulli's equation and its applications. Chapter II discusses vector analysis, including the Stokes, Gauss, and Green theorems. In Chapter III the general properties of fluid motion, continuity, dynamical equations, pressure, energy, and vorticity are studied in terms of the concise vector notation. Chapter IV presents the intrinsic properties of two dimensional motion, Chapter V the important properties of complex variables. Chapter VI represents the application of complex variables to various two-dimensional problems. Chapter VII deals with simple Joukowski airfoils, Chapter VIII with sources and sinks. In Chapter IX the moving cylinder is treated in detail and applications are made of a form of the Kutta-Joukowski theorem which includes the case of accelerated motion. Chapter X contains a discussion of the mapping theorem of Schwarz and Christoffel with some immediate applications; in Chapters XI and XII further applications are made to the discontinuous motions of jets, currents, and the wake behind a cylinder, including an account of the elegant method of Levi-Civita. Chapter XIII is devoted to the discussion of rectilinear vortices, Kármán's vortex street, and the drag due to a vortex wake. Chapter XIV deals with two-dimensional wave motion using as a basis the remarkable equation for the complex potential obtained by Cisotti.

Chapter XV introduces Stokes' stream function and the application of conformal mapping to three-dimensional problems

(*Continued on next page*)

Institute Notes

Third Wright Brothers Lecture

E. F. Relf, a Fellow of the Institute and Superintendent of the Aerodynamics Department at the National Physical Laboratory, Teddington, England, has been selected to deliver the third Wright Brothers Lecture in New York on Saturday, December 16th, 1939, as December 17th falls on Sunday. The subject will be "Recent Aerodynamic Researches in England."

The paper will cover the recent work at the National Physical Laboratory and will show the relation of this work to that being done elsewhere in England.

In addition there will be a luncheon in honor of Mr. Relf. An interesting program of luncheon talks is being arranged.

The Wright Brothers Lecturer is selected by a committee comprising all American members of the Institute who have delivered the Wilbur Wright Lecture of the Royal Aeronautical Society. He is chosen in successive years alternately among American and foreign aeronautical specialists.

The Lecture is sponsored by the Institute with the financial aid of the "Vernon Lynch Fund," established in 1937 by the late Edmund C. Lynch. Prof. B. Melvill Jones of Cambridge University and Dr. H. L. Dryden of the National Bureau of Standards, respectively, delivered the first and second Wright Brothers Lectures.

Fellows Elected

Each year the Fellows of the Institute elect, by secret ballot, ten new Fellows from the membership. Those honored this year are: J. L. Atwood, Don R. Berlin, J. P. Den Hartog, Hall L. Hibbard, Robert Insley, S. M. Kraus, William Littlewood, Robert J. Minshall, Mac Short, and Donald H. Wood.

The American Archives of Aeronautics

From time to time the Institute has received gifts of books, technical files, photographs, clippings, and models.

During the last few months the Institute has been exceptionally fortunate in this respect. Mr. C. R. Fairey of England has given $1000 to purchase English aeronautical books for the library. Mr. W. A. M. Burden has agreed to supplement the present collection of books to make the library complete for technical reference in aeronautics. Mr. Henry Ramsey has given a collection of clippings about famous flights of the past thirty years. Col. V. E. Clark has presented his valuable technical files and Major E. E. Aldrin gave his entire technical library. Fifty beautiful models and many interesting souvenirs have been received from airplane manufacturers and others. The latest accession is a gift from Mr. Hart O. Berg of Paris, who represented the Wright Brothers in Europe from 1908 to 1911. The gift comprises seven large scrapbooks of pamphlets, photographs and a complete file of clippings on early aviation.

Under the sponsorship of the Institute the Works Projects Administration has compiled a comprehensive index of aeronautical books, articles, photographs, biographies, and chronologies.

This collection is more than a library. It is more properly the beginning of an Archives of Aeronautics. The Institute intends to expand it so that it will become an extensive file of aeronautical source material.

Members are invited to send any clippings, pamphlets, or books to the Archives. Any clippings from newspapers or magazines will be useful in expanding the files. Biographical material and photographs of members are particularly requested.

Some members have expressed a willingness to bequeath their aeronautical collections to the Institute. This may be done by a letter to heirs or a clause in their wills.

Gifts

Mr. Charles L. Lawrence, Past-President of the Institute, has given to the model collection of the Institute a working model of the Wright Whirlwind engine designed by him. The model was made by Cartier and will make a valuable addition to the exhibit at the New York Museum of Science and Industry in Rockefeller Center.

Necrology

Hampton D. Ewing

Hampton D. Ewing, a Founder Member of the Institute, died at his home in Yonkers, New York, on August 5, 1939, at the age of 73.

Mr. Ewing was Chairman of the committees on air law of the Association of the Bar of New York and the New York State Bar Association. He wrote many articles on the legal aspects of aviation. At his home in the South he maintained a private flying field. He was a graduate of Columbia University and the Stevens Institute of Technology.

Book Reviews

(*Continued from previous page*)

with axial symmetry. The general motion of spheres and ellipsoids is treated in Chapter XVI. In Chapter XVII a method of partial differentiation with respect to a vector is defined and applied to obtain Kirchhoff's equations in vector form, thus replacing six equations by two. This method is new and offers opportunities for research in stability problems. Chapter XVIII discusses vortex motion in general with particular application to the airfoil of finite span. Chapter XIX gives an outline of the application of vector methods to viscous liquids and a brief description of the boundary layer theory. Not many references to original work are given, the reader generally being referred to Lamb for such details. However, the book contains a total of 508 problems which are collected into sets at the end of each chapter and greatly add to the value of the book as a text. These problems are taken principally from the university examination papers. A large number of well-drawn diagrams serve to illustrate the subject matter.

William Bollay
Harvard University

Pilot's "A" License, compiled by John F. Leeming; Sir Isaac Pitman & Sons, Ltd., London, Pitman Publishing Corporation, New York, 1938; 87 pages, $1.40.

American pilots who plan to use airplanes abroad will find this book helpful. It not only gives the requirements for obtaining a license abroad but gives answers to many of the questions that may be asked by an examiner of a pilot during his oral examination. The general notes in the latter portion of the book give a condensed summary of the information required for flying international routes, a list of all English Flying Clubs, and the regulations for obtaining permission to fly in Europe and Africa.

Aeronautical Reviews

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

Alternating Effect between Adjacent and Diverted Flow. W. Fabricius. In order that the effect between adjacent and diverted flow could be determined, measurements of the three components, pressure distribution, boundary layer, and wake were made on a wing with an adjusted center section of greater angle of attack. In the tests the flow at the center section was diverted but, on the remaining part of the wing, the flow was always adjacent. Goettingen Aerodynamic Research Institute report. *Luftfahrtforschung*, June 20, 1939, pages 309–317, 20 illus.

Comparison of the Principles of Propulsion of Cetaceans and Fish with Those of Birds. M. Tricot. Propulsive motions of fish are analyzed. Concluded. *L'Aerophile*, April, 1939, pages 88–89, 9 illus.

Aircraft Design

Bigger and Bigger. R. C. Morrison. What America has on the drawing-board for transoceanic flying, and how designers are tackling the new problems set by the outsize aircraft. Next step after the Boeing 314 flying boats are completed, will be the construction of flying boats with spans in the neighborhood of 175 to 200 ft. and weighing close to 180,000 lb. Speed is not likely to surpass 250 m.p.h.

Sikorsky, Douglas, and Boeing believe that six engines will be needed to bridge that 5000-mile gap with 100 passengers, but Consolidated are relying on four units to do the task. Engines will probably be in the 2160-hp. class. In order to build an efficient airplane of about 200-ft. span, engines in the neighborhood of 2300 hp. must be developed. Necessity for driving the propeller with a long shaft from a high horsepowered engine is referred to. It is reasonable to believe that the next boats to be built for Pan-American Airways will be powered by 24-cylinder Allison engines each developing 2300 hp. at take-off. They may consist of the "X" type, or of four banks of cylinders in fan style.

Discussion also covers: the propeller as the bottle neck in aircraft-design progress; use of superchargers; use of a large-area slot sliding forward in conjunction with a flap of the Fowler type sliding aft as going even farther than the 40 lb./sq.ft. wing-loading mark; stainless steel hulls with absence of rivets and overlapping sheet-metal joints; and wing design. Reference is made to designs proposed by Sikorsky, Martin, Boeing, Consolidated, Curtiss-Wright, and Douglas and military as well as commercial airplane designs are mentioned. *Flight*, June 29, 1939, pages 647–650, 5 illus.

Calculation of Lift and Airflow Phenomena of an Airfoil beyond Maximum Lift Region. P. Jordan. A closer insight into the airflow phenomena of the wing beyond maximum lift can be obtained by studying the fundamentals for the calculation of lift distribution under unsymmetrical airflow as occurs, for example, in a roll of the airplane due to the unsymmetrical airflow, and by comparison with measurements on wings tested with linear variation of the angle of attack spanwise. This knowledge is given through airflow observations and force measurements in irregular airflow on a wing having rectangular plan form and on one with a warped airfoil at a Reynolds Number of 2×10^5. Groundwork is laid for the calculation of desired lift distributions by means of systematic measurements. Goettingen Aerodynamic Research Institute report. *Luftfahrtforschung*, April 20, 1939, pages 184–197, 26 illus., 2 equations.

Calculation of the Symmetrical Longitudinal Motion of Aircraft. K. Solf. Equations for symmetrical longitudinal motion of an aircraft are solved in detail and discussed. Frequency and damping of slow vertical and turning oscillations are studied for forced oscillations with the aid of diagrams proposed by C. Runge. Goettingen Aerodynamic Research Institute report. *Luftfahrtforschung*, April 20, 1939, pages 198–208, 11 illus., 1 table, 27 equations.

Flow Phenomena over a Fabric-Covered Wing at High Angles of Attack in Rolling Forward Flight. M. Kohler. Author attempts to study how to obtain a better insight into difficult problems of airflow on a wing in the region of high lift. To do this he has made mathematical and experimental investigations of a stationary rectangular wing, of a rotating wing, and of a warped stationary wing. Long Goettingen Aerodynamic Research Institute report. *Luftfahrtforschung*, April 20, 1939, pages 159–177, 35 illus., equations.

Forces and Moments of a Wing in Crabbed Flight. S. Hoerner. Available measurements on straight wings, sweptback wings, and wings with dihedral are discussed in the light of a wing in crabbed flight. *Luftfahrtforschung*, April 20, 1939, pages 178–183, 10 illus., 1 table, 16 equations.

Measurements on a Low-Wing Airplane in a Rotating Airstream Compared with Full-Flight Measurements. W. Bader. Tests were conducted on a model of the BFW-M27b$_1$ airplane in a rotating airstream with the aid of the six-component balance. Tests are described and measurements are compared with results of full-scale spinning tests. D.V.L. report. *Luftfahrtforschung*, February 20, 1939, pages 104–111, 13 illus., 1 table, many equations.

Side Slip and Roll of Gull-Wing Airplanes. G. Richter. Side wind on a wing causes rolling moments which can be solved into several moments. In particular, wings having vee-form or of the gull-wing type have additional moments in the roll. A series of formulas and graphs are set up from which it is possible to determine the necessary rolling moments for the gull wing, and a mathematical example is given as an illustration. *Luftfahrtforschung*, February 20, 1939, pages 112–120, 16 illus., 29 equations.

Speed Range of Particularly Thin and Small-Cambered Airfoils. K. Jaeckel. Problem of the calculation of the induced velocity in the region of an airfoil has already been discussed before, but, according to the author, no one has succeeded in determining this velocity by means of explicit functions. The relation between the vortex sheet of thin profiles and their speed range is determined by means of simple functions, limited to the case of vanishing camber. *Luftfahrtforschung*, April 20, 1939, pages 209–211, 1 illus., 22 equations.

Transition of Pressure Distribution Measured at Optional Angles of Attack. A. Walz. Pressure distribution at other angles of attack cannot be determined exactly by extrapolation from measured values of lift coefficient at a given angle of attack. A method is proposed by which pressure distribution at a given angle of attack can be calculated with more exactness. Graphical aids and definite instructions given help to make the practical applications easy. Goettingen Aerodynamic Research Institute report. *Luftfahrtforschung*, March 20, 1939, pages 121–128, 14 illus., 8 equations.

Stress Analysis and Structures

The Air Forces of Harmonically Vibrating Flat Plates (Two-Dimensional Problem). F. Dietze. Previously known air-force laws for the smooth-flow harmonic vibration of a bent thin plate (wing with flap) are enlarged in order to include harmonic time dependence in addition to any possibility of deforming. In particular, air forces and air moments are considered for the case that deformation of the cross-section of the plate follows according to linear overlapping due to uniform tensile stress, and the known entirely rational function results. A wing with flap and tab is dealt with especially. D.V.L. report. *Luftfahrtforschung*, February 20, 1939, pages 84–96, 5 illus., 9 tables, many equations.

Airplanes, Unlimited. F. Davis. Possibility of mass production of aircraft with molded fuselages and wings of Duramold, as used in the construction of the Clark 46 airplane, is brought out, and a few details of the properties of Duramold are mentioned. *Scientific American*, July, 1939, pages 15–17, 4 illus.

Low-Density Structural Material. Col. V. E. Clark. Properties of four types of Duramold produced for use in aircraft fuselages and wings are discussed. Sections of the Clark wing showing built-in leading edge slot are illustrated in a drawing. Article is based on S.A.E. paper presented before the World Automotive Congress and previously abstracted from preprint. *Aero Digest*, July, 1939, pages 101–102, 105, 4 illus., 1 table.

General Opinions on Flutter Calculation. A. Teichmann. Methods of finding the criteria from which critical speed can be finally determined so that flutter characteristics can be guessed from similar construction. Phenomenon of flutter of wing and tail groups is presented as well as the nature of the calculation of flutter. State of the harmonic variation of the airstream, in particular harmonic flutter, is briefly described. Fundamental harmonic equations of the systems and their particular homogeneous exceptions are related to the flutter equations. With the aid of these equations it is possible to study the effect of various details of air and deformation forces on the harmonic vibration system. Critical speed of the fundamental harmonics equation is investigated with reference to flutter equations. Possibility of systematic investigations is considered as well as the possibilities of step-by-step approximation and the energy balance of the flutter procedure.

Setting up of the flutter calculations is discussed and three representations of possible aircraft constructions are considered, a truss system, a semimonocoque construction, and a suggested deformable system. Investigation is handled on the basis of mechanical and aerodynamical parameters of a more or less simplified or idealized representation system which approaches a probable aircraft construction. It is shown how the empirical equations were obtained from the original harmonic equations when certain terms were omitted or certain simplifications assumed.

Various steps in the calculation for the three types of aircraft construction are given including the schematic solution of the fundamental harmonic equations and also the flutter and empirical equations. Value is laid on such cases as assuming the transition of the original construction from elastic to infinitely rigid or infinitely elastic member. Very long D.V.L. report. *Luftfahrtforschung*, June 20, 1939, pages 283–308, 23 illus., many tables and equations.

Plywood Structures. O. H. Basquin. Making a good blue joint with phenolic resin glue, properties of this glue, the manufacture of plywood panels, and a new process for the manufacture of either flat or curved plywood using phenolic-resin glue set by heat are described. Photographs show parts of the structure of the Stearman wing; Howard wing panels; plywood aileron constructed by Waco; Bennett monospar wing construction; Beech application of plywood on tail surfaces; tail surfaces made of Haskelite plywood; and the fuselage skin of the Bennett bimotored plane molded from two-ply diagonal Haskelite, as well as the fuselage jig used. Properties of aircraft materials (steel, aluminum and magnesium alloys, spruce, birch, and birch , paper-, fabric-, and Cord-reinforced resin are given in a table. *Aero Digest*, July, 1939, pages 43–44, 47, 8 illus., 1 table.

A Repetition Process in the Analysis of a Disturbing Force on a Cylindrical Shell. H. Simon. By means of the solution presented the size of the first or first two disturbed members of a cylindrical shell subjected to a given force can be determined. Calculations are included for determining stresses in an elliptical shell subjected to the lowest single force. Report of the Aeronautical Institute of the Berlin Technical College. *Luftfahrtforschung*, February 20, 1939, pages 97–103, 6 illus., 19 equations.

Steel Castings in Aircraft. A. Finlayson. Use of steel castings in the Boeing Model 307 "Stratoliner," and the ability of steel castings to successfully compete under the most exacting aircraft stress requirements, both in kind and magnitude, are discussed. The cast steel parts included in the landing-gear assembly, various compositions for steel castings tried out and casting defects detected by Magnaflux, manufacture of these castings from a copper-silicon steel, heat-treatment methods, and dynamic testing of each new landing gear design in complete assembly by Boeing engineers are described. *Aero Digest*, July, 1939, pages 32–35, 11 illus. Similar article. *Iron Age*, July 20, 1939, pages 43–47, 5 illus.

Aircraft Accessories

Elastic-Ring Shock Absorbers for Aircraft. E. Richter. Recently elastic-ring shock absorbers have been used to an increasing extent on aircraft in which the elastic member consists of single external and internal elastic rings of steel the conical surfaces of which interlock so that a completely solid spring is formed. They can be used on all airplanes for undercarriage and tail wheels and require no special maintenance. Airplanes making the flights over the Himalayas in 1937–38 were equipped with shock absorbers of this type. They are not sensitive to heat and cold and tests have shown that at −70° temperature scarcely any change in the operation of the spring was noticeable. The springs are not sensitive to damage and tests have found that if a few rings dropped out, the operation would not be affected. *V.D.I.*, May 27, 1939, pages 652–654, 8 illus.

New Girling Aircraft Brake. Simple lightweight Girling brake described has been developed by New Hudson, Ltd. in conjunction with De Havilland for use on the Moth Minor and can be used on small trainer and private owner types of aircraft. New brake utilizes shoes which are operated through the medium of roller separators actuated by a cable-controlled tapered

plunger. Similar mechanism is employed for adjustment at the pivoting ends of the shoes. *Flight*, June 29, 1939, page 663, 1 illus. Description of automotive brake with floating segment on trailing side. *Automotive Industries*, June 15, 1939, page 711, 3 illus.

Aircraft

The Brussels Aero Show. Of the 31 machines shown by six nations at the Second International Aero Show at Brussels, July 8–23, there were five single-engined fighters, one twin-engined fighter, one dive bomber, four light and medium bombers, one torpedo bomber, one heavy bomber, six single-engined trainers, two twin-engined trainers, and assorted light airplanes. A Belgian helicopter which has been flown was shown.

The French Hanriot N.C.600 is the production version of the new race of twin-engined fighters. Both in this airplane and in the Renard single-seater fighter cooling air is drawn past the cylinders by ejector action of exhaust gases. Backward-facing exhausts to increase top speed are now general. Whereas British aircraft have narrower outlets than inlets, all foreign aircraft have bell-mouthed pipes. For the first time, German engine manufacturers show their engines with fuel-injection systems. According to current gossip some 75 percent of the German Air Force aircraft are equipped with gasoline-injection engines.

Table gives aircraft dimensions, weights, performances, and power-plant performance for nine British, seven Belgian, four French, six German, and two Dutch aircraft and three aircraft from the German protectorate of Bohemia. *Aeroplane*, July 12, 1939, pages 39–48, 12 illus., 1 table.

FRANCE

Airplanes in Test. N.C.2234 "Flammarion" long-range mail airplane is equipped with four Hispano-Suiza 12-Y-39 engines arranged in tandem and having a supercharger maintaining normal power at 3400 meters. Maximum speed anticipated at that altitude approaches 400 km./hr. and cruising speed 340 km./hr. With a total surface of 132 sq.meters the airplane should weigh 25 tons loaded with provision for fuel sufficient for a range of 8000 km. Brief note. *Les Ailes*, June 22, 1939, page 9.

The "Centre 2234" Stratospheric Transport. The "Centre 2234" differs from the "Centre 223" in the following respects: The four Hispano 14-AA engines are replaced by four Hispano 12 Ydrs engines. Wing tanks and military equipment are eliminated and tanks are located in the cases of the bomb-dropping apparatus. Four engines which are located in two engine nacelles, two driving pusher propellers, give a total of 3440 hp. Maximum speed 395 km./hr. Cruising speed 340 km./hr. Practical ceiling 4000 meters. Range 8000 km. Description of construction (but not of the pressure cabin), and photographs of pressure cabin, oxygen distribution system and apparatus for control of atmosphere in the cabin. *L'Aerophile*, April, 1939, page 82, 5 illus.

The S.E.C.A.T.-VI "La Mouette" Light Two Seater. A. Frachet. High-wing two-seater training and touring monoplane, constructed entirely of wood, is equipped with a Train 60-hp. engine, and has a cruising speed of 140 km./hr., a ceiling of 3500 meters, and a range of 450 km. Long description. *Les Ailes*, June 22, 1939, page 9, 2 illus., 1 table.

GREAT BRITAIN

Cunliffe-Owen "Flying Wing." Cunliffe-Owen "Flying Wing," the British version of the Burnelli UB-14, has two 890-hp. Bristol Perseus XIVc engines instead of 640-hp. P. & W. Hornets and differs from its prototype in that gross weight has been increased to 19,000 lb. instead of 15,500 lb. and wing loading has been increased to 23.5 lb./sq.ft. compared to 20 lb./sq.ft. Tail booms have been fully cantilevered, and the use of longitudinal fins at the top of the center section permits the use of longitudinal stringers so arranged as to provide more head room in the cabin. Hatch over the cockpit has been raised and controllable gills are provided on the engine nacelles. More flap area has been provided with the installation of fuselage flaps which augment trailing-edge type flaps on the outboard panels. Ailerons are not only narrower but also are split to prevent binding of the hinges with flexure of the wing. Long description of the Cunliffe-Owen "Flying Wing," the method developed by Burnelli and applied to the Burnelli UB-14, and results of calculations showing advantages of the airfoil body in acting as a completely effective lifting surface. *Aero Digest*, July, 1939, pages 109, 125, 2 illus.

From Fairey Giant to Jumping Giro. C. G. Grey. Mr. Grey's impressions of the Fairey C.1 giant airliner with the new Youngman flap, and the latest jumping autogiro. Control room, pressure cabin and emergency exits of the C.1 are described. It is mentioned that Youngman flaps have been tried out under a Fairey Battle with astounding results. "Judged by modern American ideas the Fairey air-liner is comparatively small, that is to say it is only a 25–30-seater. But if the first dozen work out as I know they will, there will be no difficulty about making 40-seaters to 50-seaters." Designed speed is 275 m.p.h. top and 220 m.p.h. cruising. Under each wing there is a Youngman flap which normally lies flush with the underside of the wing but when it is wanted the pilot can let it down parallel with the wing and can then tilt it to any desired angle, even to pulling it down practically at right angles to the wing and using it as an airbrake after landing.

C. R. Fairey, chatting about the future possibilities, told the author that he could visualize an airplane which would carry an autogiro arrangement to help getting off and slow alighting. Blades of the rotor would fold together and retract into a streamline box along the back of the machine when not in use. *Aeroplane*, July 12, 1939, pages 55–56, 2 illus.

Making Flying Safer. General Aircraft Cygnet low-wing cantilever two-seater monoplane goes a long way in reducing risks in flying. Although it can be stalled it will not spin even if willful attempts are made to do so. After being stalled the machine sinks in a comfortable attitude and the pilot retains adequate control. The Cygnet will actually fly at 46 m.p.h., though then sinking fast and lateral control at 50 m.p.h is said to be adequate. Cygnet has tricycle undercarriage, marked dihedral, and twin fins and rudders which features in combination provide its safety characteristics. Drawings illustrate how the rudder bar of the Cygnet is linked to the steerable front wheel of the undercarriage, and how the main wheels are carried in magnesium castings bolted into the rear spar fittings. Cutaway drawing shows location of equipment as well as structure. One 150-hp. Cirrus Major engine. Span 34 ft. 6 in. Wing loading 11.7 lb./sq.ft. Maximum speed fully loaded 135 m.p.h. at sea level. Cruising speed 115 m.p.h. Service ceiling 14,000 ft. Range 445 miles. Long description of design, structure, and performance, especially the latter. *Aeroplane*, July 12, 1939, pages 69–72, 8 illus.

Moth Successor. Structural and maintenance factors of the new De Havilland Moth low-wing two-place monoplane for training and private ownership. Perforated airbrake flap extends across the rear of the center section, and can be used to stretch or shorten the approach. Gipsy Minor four-in-line aircooled direct-drive engine delivers 50 hp. at 2250 r.p.m. and 90 hp. at 2600 r.p.m. Span 36 ft. 7 in. Maximum speed 118 m.p.h. at sea level and 115 m.p.h. at 5000 ft. Cruising speed 100–105 m.p.h. Ultimate range with extra tank 600 miles. Service ceiling 16,000 ft. Long description, characteristics, and performance and list of contributors to the Moth Minor. *Flight*, June 29, 1939, pages 656a–656e, 10 illus. Very long description with cutaway and other drawings. *Aeroplane*, June 28, 1939, pages 832–835, 10 illus.

Something Exceptional. New Messerschmitt Me.108 "Tfunia" four-seater low-wing cabin monoplane is fitted with a multiposition controllable-pitch propeller, and the new Argus As.10E engine gives rather more power than that in the Taifun of a year ago (270 hp. for takeoff). Taifun's really outstanding qualities are those of control and stability. Even at maximum speed, lateral movement of the control column is finger-light, and machine can be tipped over from vertical to vertical in the time it takes to move the column itself. Handley-Page slots and flaps are used, the latter being directly operated by means of a wheel which is on the same axis as that used for fore and aft trim. Maximum speed 196 m.p.h. Cruising speed 187 m.p.h. at 8000 ft. Stalling speed 47 m.p.h. Range at 187 m.p.h. 621 miles. Constructional details, flying qualities, characteristics, and performance. *Flight*, June 29, 1939, page 661, 1 illus. *Aeroplane*, June 28, 1939, page 839, 2 illus.

The Vickers-Armstrongs Wellington. Vickers Wellington I (two 965-hp. Bristol Pegasus XVIII engines) can carry a service load for 3200 miles at 180 m.p.h. Top speed is 265 m.p.h. at 17,700 ft. and even finer performances have been achieved on later models which have either two 1075-hp. Rolls-Royce Merlins or two 1375-hp. Bristol Hercules engines. Ratio of tare to maximum permissible loaded weight is 16,600 lb. to 27,000 lb. The Wellington normally carries five men. Fuselage, in spite of having heavily armed gun turrets in nose and tail, is clean. Narrow tapering wings with a high aspect ratio of 8.83, made economically possible by geodetic construction, are in the midwing position so that there is minimum interference between them and sides of the fuselage. Very detailed description of the airplane, its geodetic construction, and methods of manufacturing the airplane. Drawings include cutaway drawing of the airplane showing type of structure as well as location of equipment and other drawings showing methods of attachment of the structure.

Second article gives list of manufacturers contributing their materials and equipment to the Vickers Wellington. A Wellington fuselage comes out of its jig every twenty-four hours. Photographs show these stages after 8, 16, and 24 hours. *Aeroplane*, July 5, 1939, pages 17–25, 16 illus.

U.S.A.

Fairchild Trainer. Fairchild Model M-62 Trainer low-wing tandem monoplane having wide-tread landing gear, flaps, steel-tube fuselage, and all-wood wing. Designed to Air Corps requirements, the airplane was conceived as a low-wing type to simplify transition from training to service equipment. Ranger 6-410B-2A inverted engine rated at 165 hp. at 2450 r.p.m. Wing span 36 ft. Wing area 200 sq. ft. Gross weight 2300 lb. Description but no performance figures. *Aviation*, July, 1939, page 55, 3 illus. Few details. *Western Flying*, July, 1939, page 23, 1 illus.

New Aircraft. *Applegate* two-place amphibian (75–80-hp. engine, estimated maximum speed 105 m.p.h.). *Fleet* Model 60 two-seater low-wing trainer (Jacobs 250-hp. or 330-hp. engine giving maximum speeds of 164 or 191 m.p.h., respectively). *Rich* two-place twin-engined low-horsepower aircraft. *Aircraft Mechanics "Minx"* single-seater low-wing semi-cantilever monoplane (Continental A-40 engine, estimated maximum speed 104 m.p.h.). Brief references only and photographs of the last three. *Aero Digest*, July, 1939, page 68, 3 illus.

Some Acceleration. "The incredulous may be less so when they learn that momentary accelerations up to 10 g. have been frequently measured during terminal velocity dives in some of the new American high-speed fighters.—Which would seem to indicate some strange designs, for one can hardly imagine anybody putting such strains on himself on purpose." British comment in a brief note relating the experience of J. G. Taylor, American test pilot, when doing a terminal-velocity dive in a biplane dive bomber of well-known American make with a 1000-lb. bomb underneath. Accelerometer registered a momentary acceleration of 13½ g. *Aeroplane*, July 5, 1939, page 4.

Vought-Sikorsky Observation Scout. U.S. Navy's newest two-place observation scout Model OS2U-1 monoplane seaplane incorporates three aerodynamic developments which in combination make use of a monoplane feasible. Low landing speed, required for operations originating from catapults of battleships, has been achieved by use of two high-lift devices, the new deflector plate flap on the trailing edge of the wing and the dropping aileron so rigged that it serves the same function as a flap in increasing wing lift, and by wing "spoilers" supporting the ailerons at low speeds and providing rolling moments. Seaplane is the first application of spot welding to the primary structure of a production airplane. Pratt and Whitney Wasp Junior engine giving 400 hp. for take-off. Overall wing span 36 ft. Length 33 ft. 10 in. as a seaplane and 30 ft. 1 in. as a landplane, respective gross weights being 4764 and 4542 lb. *Aero Digest*, July, 1939, page 125. *Western Flying*, July, 1939, page 22.

Aircraft Accidents

Another Burn-Up. Empire flying boat "Connemara," lying at moorings at Hythe, was being refuelled from a gasoline barge alongside when the barge caught fire. Gasoline in the flying boat caught fire almost at once and within 20 minutes the boat was burned down. The "Connemara" had for about two months past been doing a 400-hr. trying-out test of the Bristol sleeve-valve Perseus engines which are to be used on the new transatlantic boats. Brief note. *Aeroplane*, June 28, 1939, page 836.

Air Transportation

The Airline Men Meet. F. Barker. Account of the Engineering and Maintenance Conference of the Air Transport Association, June 12 to 14, and brief abstracts of papers. *Western Flying*, July, 1939, pages 14–16, 21, 18 illus.

America's Bid for Supremacy in Transatlantic Air Travel. T. Park Hay. At this stage of transatlantic development in the air, attention is being given to the problem of how the United States should meet this foreign competition of government-subsidized airlines each with a specially chosen group of its own. There is also the question of allowing as many American companies as may be able to qualify to attempt to meet the Europeans, company for company. Background of training, of exploration, and of achievement, even over oceans, which has been established by Pan American in almost twelve years of air-transport experience is described. American Export Airlines plans, its Consolidated survey flying boat, and plans behind its survey flight are discussed in detail. *Aero Digest*, July, 1939, pages 24–27, 56, 12 illus.

The Completion of the Survey of the Imperial Reserve Air Route to Australia. An account of survey made by Captain P. G. Taylor and his crew in the flying boat "Guba." *Aeroplane*, June 28, 1939, pages 820–822, 4 illus.

Egyptian Commercial Aviation. Development of air transport in Egypt, especially of the Misr Airwork S.A.E., organized in 1932. *L'Aeronautique*, April, 1939, pages 161–163, 8 illus.

The Future of Air Transport Services over the North Atlantic. A. Verdurand. Important factors in the crossing without landing between Europe and the United States; superiority of high tonnages from the point of view of safety; superiority of modern flying boats for transoceanic crossings; superiority of the high-tonnage flying boat from the economic point of view; and the meteorological organization which would be the basis of safety for transatlantic air transport. *L'Aeronautique*, May, 1939, pages 169–172.

German Flying-Boat Operation for the North Atlantic. German experimental flights across the North Atlantic with the Heinkel He-58 and Blohm and Voss Ha-139-B, operating from the "Friesenland" are reviewed. The Dornier Do-26 four-engined catapultable postal flying boat (four Junkers Jumo 205 heavy-oil engines arranged in tandem and giving a total of 2400 hp.) which weighs 20,000 kg. loaded, is described in great detail with photographs of the pilot's cockpit and control instruments. *L'Aeronautique*, April, 1939, pages 139–147, 21 illus.

Japanese Air Transportation. H. Bouche. Government subsidies to the Japanese airlines, development of these airlines, aircraft used, and Japanese airline service to foreign countries such as Siam, India, and to the South Sea Islands. Maps show: Japanese airlines and their associated companies to China and Manchoukuo at the beginning of 1939 indicating the importance of Fukuoka; network of Chinese airlines at the opening of hostilities in 1936; network of the C.N.A.C. and the Eurasia in 1938; zones of control and influence of the high powers in China and successive axes of Chinese supply to the west and south; actual network of aerial connections between India, China, the South Sea Islands, and Australia; and initial transpacific program of Japanese air lines in 1935. *L'Aeronautique*, May, 1939, pages 180–186, 9 illus.

Poland. J. B. Smith. Flying conditions in Poland; LOT Airline and two other airlines operating in Poland; civil aviation expenditures 1936–39; the 40 airports operating; and photographs of Polish aircraft. *Aero Digest*, July, 1939, pages 40–42, 10 illus., 1 table.

Air Transport Lines in the Eastern Baltic. These air transport lines cover a territory the surface of which is analogous to that of France and the middle of which is occupied by the Baltic itself. Eight nations are involved, Sweden, Finland, and Germany who control nearly all the coast, the block of the three Baltic countries, Esthonia, Letonia, and Lithuania, small nations independently detached in 1919 from the old empire of the Czars, U.S.S.R. which touches the Baltic only at the end of the Gulf of Finland, and Poland which reaches it only at Gdynia through the corridor at Danzig. Forces at work in this region, both commercial and political, are discussed and map of the air-transport lines covering this area is shown. Position of nations interested in the Baltic airlines in these difficult months are considered, and air-transport lines in these Baltic countries are discussed in detail. *L'Aeronautique*, May, 1939, pages 173–179, 13 illus.

Gliders

Soaring Flight. German "DFS-Meise" high-performance glider selected for the Olympic games. Construction, aerodynamic qualities, aerodynamic brakes, and equipment of this sailplane are described in detail. Wing span 15 meters. Wing surface 15 sq.meters. Detailed descriptions also of the Italian AL-3 Olympic glider (wing span 15 meters, surface 14 sq.meters) and the Italian Pellicano glider (wing span 15 meters, wing surface 14.7 sq.meters, minimum descending speed 0.70 meters/sec.). *L'Aerophile*, May, 1939, pages 104–110, 32 illus., 3 tables.

Propellers

Composite Wood and Plastic Propeller Blades. F. E. Weick. Lightweight propeller blades constructed of wood and plastic by the Schwarz process, together with materials and methods of construction. Blade consists of a main core of laminated light wood which merges into a root of impregnated and compressed hard wood which, in turn, is threaded and screwed into a steel sleeve. Steel sleeve can be mounted in either an adjustable or a controllable-pitch hub. Rest of blade is entirely covered with a heavy coating of reinforced plastic sheet, and leading edge is protected with a flush strip of metal. Problem of efficiency is analyzed, particularly with regard to matters of service record, flutter and vibration, ease of repair, and ice formation. *S.A.E. Jour. (Trans.)*, June, 1939, pages 252–258, 8 illus., 2 tables, equations.

Experiments with Composite Airscrew Blades. F. M. Thomas and A. G. A. Tawell. Development by the De Havilland Aircraft Company of a composite blade construction which uses solid metal for carrying major loads and a light material, superimposed on it, for completing the best aerodynamic shape. Experimental work which has been carried out by the De Havilland Company is described in detail and experimental work of a radically advanced nature which is being carried on at present is outlined. Experiments include: work on the metal blade of a shape known to have good conditions for minimum stress concentration; experiments with a second fairing of Bakelized fabric made at the Royal Aircraft Establishment and wound directly on the blade at a temperature high enough to soften impregnating resin; expanded rubber fairings called Onazote; tests on molding and attachment of the fairing; weathering qualities; overspeed tests at Farnborough; and new work in removing more of the metal from the inboard portions of the blade and adding more fairing. *Flight, Aircraft Engr. Sup.*, June 29, 1939, pages 23–26, 10 illus.

Ratier Variable-Pitch Propellers in 1939. P. Leglise. Automatic functioning of the speed control mechanism in propellers with electric control. Very long detailed description of electric motors, bore for engine cannons, mechanical and magnetic contact breakers, commutators, carbons and carbon holders, regulators, and relays. Many drawings and photographs of these parts. Continued. *L'Aeronautique*, May, 1939, pages 187–202, 32 illus.

The Vortex Theory of Screw Propellers. J. Lockwood Taylor. Vortex theory of propellers, originally developed in England by Glauert for a many-bladed propeller and the later extension, with certain restrictions, by Goldstein, to propellers having a finite number of blades are discussed. Goldstein theory for predicting performance of marine propellers with errors of the order of 5 percent, and the relation between vortex theory and the older momentum theory, which has not always been appreciated, are considered. Brard has shown that a more rigid calculation of inflow due to helical vortices gives the same result as the Glauert theory for an infinite number of blades, so far as rotational component is concerned, and that discrepancy in axial component is unimportant in practice for normal propeller designs. Glauert theory is to be regarded as subject to this restriction, and an analogous limitation applies also to the Goldstein theory which strictly applies only to a blade of particular form and pitch distribution. Goldstein correction is further discussed. *Engineering*, June 30, 1939, page 765.

Miscellaneous

Aviation from Day to Day: February 1–28 and March 1–31, 1939. Records, flights and performances; commercial aviation (tests and new equipment, orders and supply, and air-transport exploration); military aviation in regard to tests and new equipment, orders and supply; accidents; and deaths. Outline of these events during the months of February and March. *L'Aeronautique*, April and May, 1939, pages 166–168 and 204–208, 10 illus.

Directory of Manufacturers of Materials and Fabricated Parts. Directory of sources of supply of aircraft and aircraft-engine materials and fabricated parts. *Aero Digest*, July, 1939, pages 146–174 (alternate pages).

Hope of Prosperity. British aviation material exported to foreign countries during the first five months of 1939 shows a considerable increase over that for 1938—a record year. Very brief note giving total amounts and names of airplanes exported to certain countries. *Aeroplane*, July 5, 1939, page 1.

Visit to Italy. C. G. Grey. Account of the International Congress of Aeronautical Journalists in Rome.

Second issue—Four-motor Piaggio transport (P.50), two-engined 310- or 312-type Capronis, Breda two-engined fighter, Fiat single-seater single-engined fighter, and the Nardi F.N.G. 15 trainer, which were exhibited at the Air Show, staged for the Congress, are referred to with a few details. The air display and flight with Il Duce as the pilot in his Savoia bomber are discussed, and an account of the trip around Guidonia is given. To be continued. *Aeroplane*, July 5 and 12, 1939, pages 5–7, 26–27, and 49–54, 20 illus.

Aircraft Instruments

Compilation and Criticisms of Published Suggestions for Determination of Distance and for Acoustic Sounding by the Radio Method. K. Dziewior. Survey of fundamentally possible methods for determination of distance by the reflection of radio waves. The published suggestions are classified as to their method of operation. Possibilities of applying such methods to the determination of the height of an airplane above the ground are discussed in great detail.

The distance-measuring processes described include: pure operating time measurement of electric impulses; production of a beat or an intermediate frequency by means of conversion of transmitter frequency; measurement of phase shift between an outgoing wave and a corresponding reflected wave; production of vertical waves; regenerative coupling of the reflected object; influence of electric magnitude by means of the reflected object; angle measuring procedure; and additional special altitude-measuring procedures. *Luftfahrtforschung*, June 20, 1939, pages 326–328, 29 illus.

Methods of Measuring Altitude above the Gound Based on Radio Principles. U. Theile. Various methods based on radio principles have been suggested in Germany and foreign countries for the measurement of the altitude of an aircraft above the ground. These methods, including the capacitance, reflection, impulse and electrical-mechanical methods, are described and criticized. *Luftfahrtforschung*, June 20, 1939, pages 339–347, 10 illus., 8 equations.

Damping Types for Vibrations of the Gyroscopic Horizon and Their Effect in Curved Flight. M. Schuler and K. Magnus. A gyroscopic horizon developed as an undamped heavy gyro pendulum may be incited to large vibrations in a turning airplane. Resonance phenomena may occur in the case of a given direction of rotation and rotational speed of the airplane. Effect of three types of damping on such vibrations is investigated, namely, nozzle damping in one precision plane, nozzle damping in both precision planes, and forced damping. In particular, reduction of resonance phenomena as the result of damping is investigated. Goettingen Institute of Mechanics report. *Luftfahrtforschung*, June 20, 1939, pages 318–324, 12 illus., 17 equations.

Airports and Equipment

Characteristics of an Artificial Basin for the Take-Off and Landing of Transoceanic Flying Boats in the Region of Paris. Maximum length which will be required by flying boats of high tonnage for take-off will be 3 km., according to French predictions. Characteristics of the proposed basin for take-off under normal conditions are given as length 4 km., width 500 meters, and orientation making an angle of less than 30° to the direction of the wind. Three take-off areas with an angle of 60° between them are necessary. Diagrams show a scheme for the artificial take-off basin, general scheme for the basin for maneuvering, and scheme for landing an airplane without visibility. *L'Aeronautique*, April, 1939, pages 136–138, 6 illus.

Materials

Automative Materials—New Developments. New surface treatment for aluminum pistons, intended to improve their wearing qualities and especially to prevent scuffing during the running-in period, has been patented by H. K. Work and C. J. Slunder (U.S. patent No. 2,157,155 assigned to the Aluminum Corporation of America). Process consists essentially in first anodizing the wearing surface of the piston and then applying a coating of deflocculated graphite to the anodized surface, the deflocculated graphite suspension being mixed with a solution of sodium silicate to insure better adherence of the graphite to the aluminum-oxide coating.

Zirconium-copper, a new material for improving standard brasses and bronzes, is now being supplied in the form of a concentrate by P. R. Mallory and Company. Zirconium not only acts as a deoxidizer and scavenger of melt, but when alloyed with manganese bronzes, aluminum bronzes, and others, it is said to give increased hardness and tensile strength, higher thermal and electrical conductivity, and improved corrosion resistance. Descriptions of these materials. *Automotive Industries*, July 15, 1939, page 58.

British Standard Specifications. Aircraft materials and parts including: high-tensile steel bolts; thin brass nuts; turnbuckles; revision covering mercurous-nitrate test adopted as a check on the tendency of brass tubes used for honeycomb-type radiators to develop cracks due to internal stresses in the hard-rolled material; aluminum-alloy sheets and aluminum-coated sheets and coils; and eyeletted fuselage webbing and its tensile breaking strength. Brief references only to these seven specifications and to those relating to testing of vegetable adhesives, cold-rolled mild-steel strip, and fusion-welded air receivers. *Engineering*, July 7, 1939, page 14.

New Equipment. Norton kerosene-lubricated grinding machines; Markal solidified paint stick for marking materials; B-line course and bearing in-

dicator; Park-Stewart flux for aluminum; Buckeye compact pneumatic nibbler; Esco Engineering small-parts pump jig; Lincoln stainless-steel welding electrode; Curran safety grease solvent for metal aircraft; new Russell Rusco seat belt; Moto-Scoot motor scooter; Adel vanetype anti-icing pump; Johnson self-lubricating bearing bronze; Farnham rolls for rolling leading-edge skins; Fuller zinc-chromate compounds for aircraft use; Stow Junior flexible tools; new aluminum alloy of the National Bronze & Aluminum Foundry which needs no heat treating; Glidden quick-drying aircraft finish; and Chicago Metal Hose resistance welding. Brief notes. *Aero Digest*, July, 1939, pages 138–139, 141–142, 8 illus., 1 table.

Metals

Atomic Patterns of Metals. W. L. Bragg. New technique of X-ray analysis as applied to the structure of metals, and results of research in the author's laboratory are discussed. Iron, nickel, cobalt, copper, and chromium were taken and their alloys with each other and with aluminum were examined. The author points out that the study of metals has made it clear that their strength comes, not from bonds between neighboring metal atoms, but from irregularities of structure. He pictures the state of affairs in a metal that has one of the simple α and β structures but which is not pure, and shows how different types of structure are obtained according to rate of cooling. Rearrangements of atoms which have a profound influence on the mechanical properties of the alloy, or age hardening, is explained. Abstract of International Foundry Congress paper. *Engineering*, June 30, 1939, page 788.

Cable Control Systems for Modern Aircraft. H. MacMillan. Tests at Wright Field having demonstrated that preforming cables would greatly extend their life, a preforming process was developed. Development of this process and of cable control systems at the Hazard Wire Rope Company since 1927 are discussed. Noncorrosive properties of various materials for these parts are pointed out. Results of tests conducted by Hazard's Research Department to ascertain the corrosion-fatigue characteristics of stainless-steel control cables, and stretch of control cables are described. Properties of carbon steel and stainless steel for cables are compared in a table. *Aero Digest*, July, 1939, pages 48, 51, 114, 3 illus., 1 table.

Iron and Steel

"Five-Point" Deephard Steel. Going beyond development of the "Five-Point" process and its application to all S.A.E. low-carbon steels, Foote Brothers Gear and Machine Corporation has collaborated with a large alloy mill in developing a special-analysis, a nickel-molybdenum steel which, when processed by the Five-Point Deephard steel process, shows the following core physical properties: 156,000 lb./sq.in. yield point; 216,000 lb./sq.in. ultimate strength; 11 percent elongation in 2 in.; surface Brinell hardness of 725. Penetration of "wear life" hardness in "Five-Point" Deephard Steel, as compared with carburized steel and high-carbon "hardened processed" steels is shown in a graph. "Five-Point" hardening procedure described is said to impart high surface hardness, great depth of hardness, and a gradual fusion of this hardness with core area. *Iron Age*, July 13, 1939, page 81, 1 illus. *Automotive Industries*, June 15, 1939, pages 704–705, 718, 4 illus., 2 tables.

Nitrided, Oil and Air Hardened Steels. E. Eichwald. Survey of the strength properties, heat treatment, and applications of German steels of these types. *A.T.Z.*, June 25, 1939, pages 338–343, 8 illus., 4 tables.

The Thermal Conductivity of High-Duty and Alloy Cast Irons. J. W. Donaldson. Investigations to determine the influence which alloy additions exert on the heat-conductivity property of cast iron with a view not only of determining the effect of the combination of alloying elements already experimented with, but also to determine the effect of new alloying elements, while at the same time obtaining reliable data on the thermal conductivity of such irons.

Thermal conductivity of grey cast iron is lowered by copper in a manner similar to that in which it is lowered by silicon and nickel, the influence of copper being approximately half that of silicon. Molybdenum tends to raise the thermal conductivity and acts in a similar manner to chromium and tungsten, although its influence is not so pronounced. Where nickel and chromium or nickel and manganese are alloyed together in cast iron, the influence of nickel in lowering the thermal conductivity is counteracted to a slight degree by the chromium or manganese. A large proportion of nickel has a pronounced influence in lowering the thermal conductivity but where part of the nickel is replaced by copper the influence is not so marked. Aluminum, even in the presence of chromium, has a very pronounced influence in lowering the thermal conductivity of grey cast iron. International Foundry Congress paper. *Engineering*, July 7, 1939, pages 26–28, 5 illus., 17 tables, equations.

Testing of Metals

Fatigue of Metals—Developments in the United States. H. F. Moore. Effect of "stress raisers"; fatigue damage by occasional overstress; detection of early stage of a fatigue crack; effect of chemical composition; correlation of metallography and mechanical properties; study of fatigue failure by X-ray diffraction; endurance limit and cycles of stress; speed of stress travel and fatigue strength; question of whether perfectly elastic metals are desirable; and fatigue testing in special fields. Concluded. *Metals & Alloys*, June, 1939, pages 180–183, 3 illus.

Function of Temperature in the Fatigue of Metals in the Case of Static and Alternating Stresses. G. Guertler and E. Schmid. Function of temperature in the constant and alternating strength is demonstrated by a series of examples dealing with steel, aluminum alloys, and pure aluminum and copper. As a rule, in the case of low temperature, fatigue limit is greater than the alternating strength. It drops more rapidly with rising temperature and, beginning with a given "sudden change of temperature," it has lower tension values than the alternating strength. Function of temperature in the fatigue limit in an extensive temperature range is well expressed by the formula: $\sigma_D = \alpha + \beta\sqrt{T}$ which is the function derived from the Becker-Orowan theory of crystal plasticity. Importance of dyanamic creeping strength for fatigue is discussed diagrammatically, and the necessity for development of measuring methods for determining rate of creep by means of alternating fatigue tests with initial loading is pointed out. *V.D.I.* June 24, 1939, pages 749–752, 10 illus., 2 tables, equations.

Inspection by X-ray. R. C. Woods and E. K. Hight. Accurate and unbiased picture of X-ray inspection and its value to the aviation industry as a whole. In the long run, the ideal setup is to radiograph before and after machine work. With the former, extremely poor pieces are rejected, and with the latter, defects are discovered which previously had been missed or which has been caused during machining or bending processes. Explanation of the electron stream, various energy transformations occurring between X-rays and matter, the radiograph, magnetic methods and their defects in testing aircraft substances. internal flaws disclosed by X-rays, X-ray inspection of aircraft castings, and fluoroscopic examination of aircraft materials are covered. *Aero Digest*, July, 1939, pages 36–38, 105, 8 illus.

Tensile Testing in the Manufacture of Wire. G. C. Stauffer. Vertical inclination balance type of wire testing machine made by Henry L. Scott Company shows graphically on a chart the characteristics of the wire so clearly that tensile properties are revealed without need for calculation. Factor of elasticity, wires for radio tubes, zinc wire, and testing in research are discussed. *Metals & Alloys*, June, 1939, pages 173–176, 8 illus.

Thermoflux Measures Plate Thickness. A. V. de Forest. Thermoflux thermal process described, offers a convenient method of field inspection for wall thickness measurements where only one side of the metal is available for test. Measurement is made by applying a controlled rate of heat application for a limited time, and measuring the resulting rise in temperature. For steel boiler plate, heat is most conveniently generated in the metal itself by an a.c. magnetic yoke held in contact with the surface. Between the legs of the yoke a thermocouple is applied, and rise in temperature after a definite length of time is used as the thickness indication. Test results are also described. *Iron Age*, July 13, 1939, pages 82–85, 6 illus.

Nonferrous Alloys

Anodically Oxidized Aluminum Alloys—Metallographic Examination. F. Keller and G. W. Wilcox. Effects of electrolytic oxidation on the color and uniformity of appearance of anodic coating on aluminum alloys containing a variety of constituents. It is shown by several methods of metallographic examination that size and distribution of the microconstituents may have important effects on the oxidation characteristics. Tendency of some anodically oxidized aluminum-alloy samples to develop a streaked appearance during the treatment is influenced by the amount, size, distribution and oxidation characteristics of the microconstituents. Because of these facts some aluminum alloys are found to be more suitable for anodic oxidation than others. Results of extensive investigation conducted by the Aluminum Research Laboratories, and description of methods used for examination of oxide coatings. *Metals & Alloys*, June, 1939, pages 187–195, 31 illus.

Bismuth for Fusible Alloys, Models and Matrix Work. Continuation of the discussion of "The Right Metal in the Right Place," designed to aid manufacturers in selecting the most suitable non-ferrous metal or alloy for their products. Primary use of bismuth as a constituent of low-melting alloys, and properties of alloys with bismuth are discussed with a selected list of fusible alloys and their flow temperatures, freezing ranges, compositions, and uses. *Iron Age*, July 20, 1939, pages 40–42, 2 illus., 1 table.

Copper and Copper Alloy Castings. H. J. Miller. Properties of precipitation-hardening casting alloys, and foundry technique with special reference to melting procedure and molds and mold metals. Condensed version of discussion of the paper is included. Concluded. International Foundry Congress paper. *Metal Industry*, June 30, 1939, pages 689–692, 1 table.

Inconel in Aircraft. C. A. Crawford and J. M. Weldon. Properties of Inconel with special reference to its technical qualifications for heat- and corrosion-resistant applications in aircraft exhaust systems. Suitability of Inconel for high-temperature work, and results of usage and tests are discussed. Properties of Inconel at high temperatures (70° to 1775°F.) and the inherent strength of Inconel sheet and metallic arc welds are given in tables. *Aero Digest*, July, 1939, pages 94, 97–98, 7 illus., 3 tables.

Magalloy Castings. Magalloy magnesium-alloy castings, made by the Magnes Fabricators Division of Bohn Aluminum and Brass Corporation, weigh about two-thirds as much as aluminum castings or approximately 20 percent of the weight of steel. They have great uniformity of physical properties, machine easily, are structurally sound and free from internal porosity, and show no tendency toward pinholes. Resistance to corrosion, welding, average properties of Magalloy sand castings, and Magalloy specifications are dealt with. *Aero Digest*, July, 1939, pages 52, 55, 7 illus., 2 tables.

The Melting of Light Alloys. A. J. Murphy, S. A. E. Wells and R. J. M. Payne. Effect of different variables on the quality of aluminum and magnesium-alloy castings. Equipment, contamination by impurities, change of composition, and effect of temperature attained by molten metal, especially in regard to aluminum alloys are discussed. Results of chemical analysis, Brinell hardness determination, and tensile tests showing effect of repeated melting of Ceralumin "B" are shown in a table. To be concluded. International Foundry Congress paper. *Metal Industry*, July 7, 1939, pages 7–10, 1 illus., 1 table.

Research on Non-Ferrous Metals. New laboratories of the British Non-Ferrous Metals Research Association are described including melting shop; galvanizing and welding shop; equipment in the mechanical testing laboratory for mechanical, cupping and creep tests; physics laboratory; equipment for metallography, pyrometry and heat treatment; and the chemistry and corrosion laboratories.

Second article entitled "The Year's Activity in Research" covers the Association's Nineteenth Annual Report, dealing with: research program; melting and solidification of aluminum castings, bronzes and nickel silver and segregation in ingots and castings; properties of lead, copper alloys for high-temperature service, and soft solders and the deep drawing of metals; oxidation, scaling, corrosion and protection in regard to galvanizing and zinc coatings, condenser-tube corrosion, corrosion of copper and of lead; metallurgical applications of the spectrograph; electrodeposition of metals; surface quality of rolled brass and copper; and weldability of nonferrous metals. *Metal Industry*, June 30, 1939, pages 683–688, 2 illus. Description of Laboratories of the British Non-Ferrous Metals Research Association. *Engineer*, June 30, 1939, pages 794–795, 4 illus. *Engineering*, July 7, 1939, pages 12–13, 3 illus.

Plastics

Methylolthioureas. F. Pollak. Methods for making monomethylolthiourea from thioureas and formaldehyde in acid solution and in alkaline solution; conversion of monomethylothioureas from 1 into its isomer by sodium hydroxide; and dimethylolthiourea from thiourea and formaldehyde in acid solution and in alkaline solution. *Modern Plastics*, June, 1939, pages 45, 74, 76, equations.

Rubber

Synthetic Buna Rubber in Automotive Construction. H. Roelig. Types of Buna rubber, and their properties and applications in automotive construction. Properties of Perbunan are compared with those of natural rubber, and Buna S and Buna hard rubber are referred to. *A.T.Z.*, June 25, 1939, pages 330–331, 3 illus.

Miscellaneous Materials

Helium in France. Possiblities of obtaining helium in France or in its colonial empire, and a table of the analysis of explosive carbureted hydrogen gas. *L'Aerophile*, April, 1939, page 89, 1 table.

Bearings

Aluminum-Tin Bearing Metal. R.R.AC9 aluminum-tin bearing alloy was developed by Rolls Royce to combine the advantages of white metals with those of copper-lead alloys. In addition to these advantages, alloy is said to possess the bond and strength of silver which is used as a bearing metal in the United States. R.R.AC9 has the following analysis: tin 5.5 to 7.0 percent; nickel 1.5 to 1.8 percent; copper 0.6 to 0.9 percent; magnesium 0.7 to 1.0 percent; silicon 0.15 to 0.3 percent; iron 0.2 to 0.45 percent, and remainder aluminum.

Properties and tests are described. Results of tests in the center main bearing of a Rolls Royce Kestrel aero engine, showing that the die-cast AC9 bearings were able to run 23 times as long as white-metal bearings under full-load conditions, are discussed. Material is manufactured by Wellworthy Piston Rings, Ltd. *Engineering*, June 30, 1939, page 789.

Fuels and Lubricants

Determination of Tetraethyllead in Gasoline. G. Calingaert and C. M. Gambrill. Tetraethyllead in gasoline is determined quantitatively by refluxing the gasoline with concentrated hydrochloric acid, extracting the lead chloride with water, and determining the lead found by any of the standard methods. New method yields results with a mean error of only —0.012 ml. of tetraethyllead per gallon of gasoline, and precision is greater than that for the bromide method. Process described. *Industrial & Engineering Chemistry, Anal. Ed.*, June 15, 1939, pages 324–325, 1 illus., 1 table.

Engine Design and Research

Critical Speed of a Turbine Rotor. J. Morris and S. J. E. Moyes. Approximation for the lowest critical speed of a turbine rotor, which consists essentially of a composite concentrated load on a shaft running on two short bearings, is readily found by an appropriate use of Dunkerley's empirical rule for determining whirling speeds, the load being subdivided into a convenient number of elemental loads to which the Dunkerley rule is applied. Rational derivation of Dunkerley's rule is explained with an indication of a simple means of applying it to the kind of problem considered. Published with permission of the British Air Ministry. *Engineering*, June 30, 1939, pages 763–764, 4 illus., 1 table, many equations.

Detonation Process and Combustion Chambers. K. Zinner. Points of view on and consequences of detonation; research on the detonation process; the displacement process; the explosion wave; detonating vibration; tests on combustion chambers and detonation; chemical-physical fundamentals of the detonation process; reaction rate of heat explosion; the series explosions; and application of the conceptions of reaction kinetics to the combustion of the mixture residue. Very long discussion. *A.T.Z.*, May 15, 1939, pages 251–259, 19 illus.

Development and Dimensions of High-Power Engines, in Particular Aircraft Engines. F. Jaklitsch. Influences upon which increase of power principally depends for engines developing over 1000 hp. Effects of stroke-bore ratio and continuous output, operating value, engine power, mean effective piston pressure, weight per brake horsepower, progress in development, and cost of manufacture are discussed in detail. *A.T.Z.*, May 25, 1939, pages 273–287, 33 illus., 5 tables, 33 equations.

Dimensional Analysis of Turbo-Blower Stage Performance. G. G. McDonald. Application of dimensional methods to the analysis of the performance of geometrically similar fans and centrifugal pumps, dealt with in previous issues, is extended to embrace the case of an uncooled or completely cooled turbo-blower stage which is pumping a compressible fluid such as gas or superheated vapor. Dimensional relationships applied to the performance of an aero-engine gear-driven supercharger of the Rateau star wheel type, as given by R. S. Capon and G. V. Brooke, are quoted and compared with those of the author. *Engineer*, June 30, 1939, pages 800–801, 2 illus., 20 equations.

Piston Ring Developments. If piston rings are tested with respect to roundness, by surrounding them with a steel band and applying tension to the ends of the band until the gap has been closed to the predetermined value in the cylinder, and by then measuring diameters in line with the gap and at right angles thereto, correctly proportioned "expanded" rings always show a larger diameter in line with the gap than at right angles. Piston rings produced in accordance with the current German standard, which is based on a ratio of 1:25 between the radial thickness and the nominal diameter, give radial specific pressures of from 14 to 17 lb./sq.in., if a gap length of 12 percent of the diameter is assumed and the modulus of elasticity of the material is of the order of 14,000,000 lb./sq.in. Higher specific pressures can be obtained only by increasing the ratio of radial thickness to nominal diameter, and it has become the practice to use a ratio of 1:23. Abstract from *A.T.Z.*, May 25. *Automotive Industries*, July 15, 1939, page 88. *A.T.Z.*, May 25, 1939, pages 290–292, 9 illus., 1 table.

The Significance of Firing Sequence for Engine Design. H. Schroen. Definition of ignition sequence, how it is brought about, what it should be for a given number of cylinders, if it should be applicable, and what the condition of the vee engine shaft is. Very long detailed article. *A.T.Z.*, May 15, 1939, pages 242–249, 40 illus.

Thermodynamics of the Flow in the Supercharging Process of Internal Combustion Engines. H. Pfan. Problems which are discussed on the supercharging of internal-combustion engines for vehicles and aircraft, are based on the thermodynamics of flow and have arisen as a result of the trend towards increase of speed and greater r.p.m. The supply head and efficiency of the supercharger and the air intake work in the case of vehicle and aircraft-engine superchargers are calculated. *A.T.Z.*, May 25, 1939, pages 269–272, 3 illus., 9 equations.

Engine and Fuel Testing

The DVL Spark-Plug Thermal Element. H. H. Berg. Spark-plug thermal element described was developed by the D.V.L. for temperature measurements on engines. Recording apparatus is under the full ignition voltage so that a suitable insulation of the apparatus and electric connections is necessary. Temperature values depend on: actual gas temperature, time sequence of temperature variations, material of the center electrode, and spark-plug heat (that is, heat value) and carrying off of the heat by the spark plug (that is, cooling of the measuring spark plug). *A.T.Z.*, June 25, 1939, page 348, 3 illus.

The Measurement of Engine Power during Flight. General discussion of the obstacles to be overcome in measuring engine power during flight. It may be asked whether there is no method which would be applicable to aircraft similar to the measurement of the draw-bar pull of a locomotive. Such a method would involve measuring pull exerted by a tractor propeller, or the push given by a pusher propeller; in either case it requires that longitudinal force in the shaft between propeller and engine should be measured. This, as it happens, is an exceedingly difficult thing to do. It has been attempted by measuring the thrust on the engine bearers, treating engine and propeller as one. But such plans cut across the rather precise methods of engine mounting and, though possible in theory, have not been distinguished by success in practice. Hence measurement of torque rather than thrust is the better channel by which to proceed, and by that path a certain degree of success has already been found to be attainable. *Engineer*, July 14, 1939, pages 34–35.

Testing of Diesel Fuels. H. Ernst. Fundamentals of the methods possible for testing Diesel fuels. For evaluation in engine operation the method with variable compression and variable ignition delay is applied. Purpose of the investigation at the Stuttgart Institute of Motor Vehicles was to develop the method of variable ignition delay and constant compression since it is the only method which does not alter the operating conditions of the engine during tests, and it corresponds to the present-day motor-vehicle engine. This method is applicable for any fuel to the various engine methods as well as for Diesel fuels. Prerequisites for this application have been met with to such an extent that only the effects of certain limiting values on the test remain to be investigated. Description of method. *A.T.Z.*, April 25, 1939, pages 213–221, 20 illus.

Engines

Aircooled High-Altitude 450-Hp. Aircraft Engine. Argus As.410 12-cylinder inverted-vee 450-hp. aircraft engine for high-altitude operation. The supercharger is driven through an elastic coupling, and is intended for producing 360 hp. at 3000 meters altitude. Its efficiency, including drive loss is 73 percent. Parts of the supercharger are illustrated. Engine bore 105 mm. Stroke 115 mm. Swept capacity 12 liters. Compression ratio 6.5. Weight 300 kg. Take-off power 450 hp. at 3250 r.p.m. Output at ground evel 360 hp. at 3000 r.p.m. Fuel consumption in cruising flight 190 g./hp.-hr. Description. *V.D.I.*, May 27, 1939, pages 663–664, 3 illus.

British Diesel Engines. Detailed development and modification only of the following British automotive Diesel engines: A.E.C.; Ailsa Craig; Albion; Atlantic; Blackstone; Crossley; Dorman; English Electric; Ferry; Gardner; Leyland; National; Nemesis; Paxman; R.N.; Ruston Hornsby; Sirron; Stuart; Thornycroft; Tilling-Stevens; Victor; and White. *Automobile Engineer*, June, 1939, pages 178–185, 21 illus.

Continental Oil Engines. Ceskoslovenska Zbrojovka two-stroke 9-cylinder air-cooled radial aircraft engine still under development has been flown for many hundreds of hours, and attention is now being devoted to research on short-period overload outputs for take-off purposes. Already 300 hp. is being produced with satisfactory results. Combustion pressure has been raised from 1068 to 1150 lb./sq.in., while fuel-injection pressure has been reduced from 4400 to 3150 lb./sq.in., although constructionally the engine is not changed. Bore 120 mm. Stroke 130 mm. Swept capacity 12,232 c.c. Rated output at ground level 260 hp. at 1560 r.p.m.

Latest Clerget Diesel has sixteen water-cooled cylinders arranged in two banks at an angle of 45°. Bore and stroke 180 and 200 mm., respectively. Compression ratio 12:1. Rated output 1600 hp. with an overload (5 min.) of 1800 hp. and a peak (30 sec.) of 2000 hp., all at 2000 r.p.m. Unit is supercharged by four Rateau exhaust-turbo blowers mounted above the cylinder heads, each serving four cylinders. Total weight 3960 lb. Clerget 14-cylinder radial of the four-stroke type operates on the direct-injection system. Bore 140 mm. Stroke 160 mm. Compression ratio 13:1. When supercharged this unit develops 600 hp. at 1930 r.p.m. and weighs 1518 lb. or 2.53 lb./hp. Permissible overload (5 min.) at take-off 600 hp. and 700 hp., respectively, and peak outputs (30 sec.) 750 hp. at 2000 r.p.m. and 950 hp. at 2400 r.p.m.

Development is still continuing on the Coatalen aircraft engine and dry weight has been further reduced to 1100 lb. Maximum rated output 575 hp. at 2000 r.p.m. or 1.91 lb./hp. Engine is supercharged by a centrifugal blower mounted at the rear and driven at ten times crankshaft speed, maintaining atmospheric pressure at 10,000 ft. Auxiliary air-cooling for the main bearings at the same time assists in keeping down temperature inside the crankcase. No change has been made to the four Junkers opposed-piston two-stroke engines. Descriptions of these engines are contained in an article dealing in general with continental oil engines for trucks and buses. *Automobile Engineer*, June, 1939, pages 186–214, 83 illus.

Ken-Royce 7F Seven-Cylinder 120 Horsepower Engine. Rearwin Ken-Royce Model 7F 7-cylinder radial aircraft engine is a development of the Model 7DF, and is rated at 120 hp. at 2225 r.p.m. It is designed to permit many subassemblies resulting in easier production. Bore 4.25 in. Stroke 3.75 in. Displacement 372 cu. in. Compression ratio 6.1:1. Weight 285 lb. Fuel consumption 0.57 lb./hp.hr. Oil consumption 0.015 lb./hp.hr. Long description. *Aero Digest*, July, 1939, pages 118, 121, 6 illus. Long description. *Aviation*, July, 1939, pages 58, 95, 2 illus., 1 table. Shorter description. *Western Flying*, July, 1939, page 24, 1 illus.

Lycoming 65. Although the Lycoming Model O-145-B four-cylinder horizontally opposed air-cooled aircraft engine is rated at 65 hp. (2550 r.p.m.), it develops 75 hp. at 3100 r.p.m. Cruising power of 47 hp. is available at 2300 r.p.m. using 73-octane fuel. Weight with single ignition 155 lb. Fuel consumption 5½ gal./hr. at full throttle and 3¾ gal./hr. at cruising. Bore and stroke 3⅛ × 3½ in. Displacement 144.5 cu. in. Compression ratio 6.5:1. Description. *Aviation*, July, 1939, page 66, 2 illus. Description. *Western Flying*, July, 1939, page 23.

The Minié Horus Engines. Horus 4-DO 4-cylinder opposed aircraft engines are made in five versions, the 1500-cu.cm. version giving 35 hp., the 2000-cu.cm. 45/50 hp., the 2200-cu.cm. 50/55 hp., the 3000-cu.cm. 65/70 hp., and the 3170-cu.cm. 70/75 hp. Engines have two gasoline pumps, an oil pump, and special installations for equipping the engines with lighting dynamos, and hand or electric starters. Few details, drawing, photographs and performance curves. *L'Aerophile*, April, 1939, page 87, 4 illus.

Warner 7-Cylinder 165 Hp. Super-Scarab. Super-Scarab Model 165 dual-ignition 7-cylinder radial aircraft engine rated at 165 hp. at 2100 r.p.m. and 175 hp. at 2250 r.p.m. for take-off. Bore 4.625 in. Stroke 4.25 in. Displacement 499 cu.in. Compression ratio 6.4:1. Weight (dry minus hub and starter) 332 lb. Fuel consumption at 165 hp. 0.58 lb./hp.hr. and oil consumption 0.025 lb./hp.hr. Overall diameter 37.25 in. Long description. *Aero Digest*, July, 1939, page 110, 1 illus., 1 table.

Wright G-200 Series Cyclone Engines. Model G-205 is rated at 1200 hp. for take-off, 1000 hp. for normal operation from sea level to 4500 ft., and 900 hp. at 14,500 ft. and has a two-speed supercharger. Model G-202, with a single-stage supercharger, carries its 1000 hp. rating from sea level to 4500 ft. The G-200 Cyclone may be supplied with a reduction gear unit of 3:2 or 16:9. Cylinder fins are more closely spaced and deeper than those of the G-100 series. Heads have been redesigned for the deeper fins, new valve ports, valves and valve seats, and head attachment features increased shrink and form fit threads. Displacement 1823 cu.in. Bore 6.125 in. Stroke 6.875 in. Compression ratio 6.7:1. Dry weight 1302 lb. or 1.08 lb./hp.

Long description of Wright G-200 Series Cyclone 9-cylinder radial air-cooled aircraft engines made available for domestic and export sale. *Aero Digest*, July, 1939, pages 113–114, 4 illus. Long description. *Aviation*, July, 1939, pages 56, 90, 95, 3 illus. Short description. *Western Flying*, July, 1939, page 22.

PARTS AND ACCESSORIES

Deco Fuel-Injection Pump—Multi-Unit PNA Type. Multiple-unit fuel-injection pump of the Diesel Equipment Corporation. Stroke of the plunger is constant, delivery per cycle being varied by a spill valve opened by the centrifugal governor and subject also to hand control. Governor not only limits the speed at which the engine can operate, but also automatically varies the timing of the beginning of injection in accordance with engine speed. A variable-capacity constant-pressure fuel-transfer pump also forms part of the equipment. Type PNA injection pump is suitable for Diesel engines up to 120-cu.in. displacement per cylinder. Long description. *Automotive Industries*, July 15, 1939, pages 77–78, 3 illus.

Eisemann Magneto for Light Engines. Eisemann Model AM-4 magneto has been specially developed for engines of from 2 to 6 cylinders, opposed or inline. It incorporates in a single casting the mounting flange, short iron laminations for housing pole shoes and winding core seat, as well as the end plate fit ring and seats for oil seal and drive-end ball bearing. Short description and reference to the Type IS-7 impulse starter used in conjunction with the AM-4 magneto. *Aero Digest*, July, 1939, page 122, 2 illus.

Holley Carburetor—Model CG for Aircraft Engines. Carburetor has a single air passage to which fuel is supplied from a single supply chamber as a result of difference in pressure in the supply chamber and throat of the air passage. Float mechanism of the conventional supply chamber is replaced by a diaphragm mechanism, and air passage is controlled by a variable venturi instead of by a butterfly valve. Carburetor is said to be inherently free from ordinary icing troubles, owing to arrangement of the discharge nozzle and venturi throttles. Partial compensation for changes in altitude is supplied by the type of fuel-metering system and throttle used, but to permit of more exact altitude adjustment and increased economy under favorable operating conditions, a manual mixture-ratio control is provided. Long description illustrated by drawings. *Automotive Industries*, July 15, 1939, pages 60–62, 4 illus.

Injection for Engines. J. Jalbert. Process of gaseous injection described permits, without supercharging, an average effective pressure of 8 kg./sq.cm. at about 3000 r.p.m. to be obtained. Fuels of various viscosities can be used by this process, and a precision of workmanship superior to that in the production of engines in series is not required. Injection system is designed to conserve the quality of the pneumatic mixing while improving the mixing of the fuel with air by distributing it over a much longer period. Mixing by spray and diffuser, universally adopted on engines with preliminary mixing, is substituted for the method of proportioning by means of the liquid pump employed on Diesel engines.

Engine cylinder operating on the four-stroke cycle carries an injection cylinder in which a piston is displaced which is controlled by a connecting rod articulated to the crankpin of a shaft turning at half the speed of the driveshaft. According to the relative vacuum created in the injection cylinder, a suction is produced on the carburetor which is regulated to furnish a carbureted mixture rich in fuel, quantity of the latter corresponding in the nominal charge to weight of air continued in the engine cylinder in order to obtain total combustion. Mixture held in the injection cylinder, of a very great richness, is also compressed by the piston and injected in two phases as it is exposed much later.

Distribution of the two injections by the periods and by quantity, transformation of fuel in the course of injection, and variation of the charge are discussed. *L'Aeronautique*, April, 1939, pages 155–157, 4 illus., 4 equations.

New Mean Pressure Control Device. F. Eckhardt and Schlickenrieder. By means of the Henschel mean pressure control a more advantgeous effect of engine torque has become possible through more simple means than heretofore. In the new method, reduction required of the full-load quantity delivered in the case of high r.p.m. is attained by setting of the normal control rod. The centrifugal force control, intended for no load and final r.p.m. control, is joined to the injection pump and is used for the mean pressure control. Description. *A.T.Z.*, April 25, 1939, pages 235–236. 5 illus.

Remedies for One Cause of Fire. E. Albert. Two small devices designed by St. G. Hadjikakis of Athens are described which, in the case of fire of one of the engine carburetors, prevent the interruption of engine operation by assuring normal flow of the other carburetors. They immediately limit the fire to the consumption of the quantity of fuel contained in a chamber of the carburetor.

One called "anti-retours" obstructs the flowing back of the vapors of gasoline toward the tank and, accordingly, by means of its safety valve permits the evacuation of these vapors. The other device, called "clapet ou robinet automatique," stops automatically, in a minimum of time, the arrival of the gasoline very near a carburetor on fire and isolates it from the other carburetors. At the same time it warns the pilot visually or audibly. The engine can continue to operate, its other carburetors being normally supplied with fuel.

Device is illustrated and described, and results of recent studies made on fires in engine carburetors are discussed. *L'Aeronautique*, April, 1939, pages 153–154, 4 illus.

Aircraft Radio

Aero Radio Digest. *Bendix Type MN-26A* radio compass providing visual unidirectional left-right course indication simultaneously with aural reception of modulated or unmodulated signals, visual indication of off-course loop settings, and aural reception with either the electrostatically shielded loop or fixed antenna; Type MN-28A remote control unit; new Type MN-22A azimuth indicator and control; and dynamometer Type IN-4A left-right indicator. *RCA* dry cells for Models AVR-15 and AVR-15A receivers. *Wolff "Air Pilot"* radio direction finder operating on the maximum response principle invented by M. Sandford. C.A.A.'s ground-to-aircraft radio teletype equipment. Description of this radio equipment, and list of 215 aircraft radio units approved by the C.A.A. to date. Small portable receivers covering the standard broadcast and airways radio range are described briefly, including: Learadio ARP-1 portable receiver usable on the ground or in the air; RCA "New Yorker" Model 5Q8 receiver for non-portable ground use; Lafayette Model D-56 receiver; and Air Radio "AR-Port" and "AR-Airman" receiver and "AR-Autobeac" converter. *Aero Digest*, July, 1939, pages 133–134, 137, 12 illus.

Radio Procedure on American Export Airlines. H. W. Roberts. American Export Airlines will rely for their communications on the existing ground-station radio facilities on both sides of the Atlantic, rather than constructing and maintaining a ground-station network of their own. Facilities which have been made available are outlined and principal ground radio navigation, communication and meteorological facilities are shown on a map. Flying equipment installed on board the Consolidated flying boat features greater power, greater range, greater use of radiotelephony, direct use of radiotelephony by the pilot, direct use of radio direction finder by the navigating officer and duplicate transmitters and receivers. This equipment is described in detail, and a block diagram of radio installation aboard the Consolidated survey ship is shown. Radio operating schedules are given. *Aero Digest*, July, 1939, pages 28–30, 6 illus.

Photography

Automatic Aerial Photography for the Pilot Alone in an Airplane. R. Henrard. The Richard Labrély planiphote for taking photographs, due to a remote control device, can be directed between the horizontal and the vertical. The displacement of the apparatus in site is transmitted to a sighting device which is located near the eye of the pilot and attached to a lateral window of the airplane. This equipment is illustrated and its use by the author in taking aerial photographs is described. Several aerial photographs of Paris taken by the author are shown. *L'Aeronautique*, April, 1939, pages 149–153, 11 illus.

Book Reviews

Gliding and Soaring Manual, compiled by GUSTAVE SCHEURER, R. E. FRANKLIN, ARTHUR L. LAWRENCE, RICHARD C. DUPONT, LEWIN B. BARRINGER, HENRY WIGHTMAN, THEODORE BELLÁK, and KARL O. LANGE for The Soaring Society of America; Stone Aircraft Company, Detroit, Michigan, 1938; 74 pages.

The Soaring Society of America, the organization responsible for the widespread interest in gliding and soaring in this country, deserves great credit for making this manual available to pilots of this type of aircraft.

A short introduction traces the history of gliding and soaring in this country and abroad and takes up briefly the training requirements and sporting features of the art.

Chapters are devoted to: "Important Principles of Gliding Flight," giving nomenclature and explanations of aerodynamic forces and maneuvers; "Gliding and Soaring Equipment," with short descriptions of the primary glider, utility glider, sailplane, and the instruments required; "Launching Methods," including fairly complete descriptions of shock cord, auto, winch, and airplane methods of towing and launching, along with specifications and lists of precautions for the pilot and operator of the towing mechanism; "Primary Flight Training;' "Primary Soaring Instruction;" and "Soaring Meteorology."

The manual makes interesting and instructive reading. While the experienced operator will find little he does not already know, the material will be invaluable for beginning and prospective glider and sailplane pilots.

The Testing of Metallic Materials, by ERNEST SKERRY; Bunhill Publications, Ltd., London, 1938; 51 pages, 3s. 6d.

The subject matter of this book covers a large number of techniques for the testing of metallic materials as well as the interpretation of the test data. The separate chapters have appeared at various times in *Aircraft Engineering*.

The material covers fundamental laws and definitions, tensile machines, hardness tests, and various miscellaneous extension, ductility, bending, and torsion tests. The most space is devoted to the various hardness tests; descriptions of the Brinell, Vickers, Amsler, Rockwell, Shore, Herbert (cloudburst and pendulum), and Izod impact tests are given, as well as some material on the correlation of Brinell and Rockwell numbers.

The book is illustrated with photographs of machines and typical test results. It should serve as a handy guide to the techniques of materials testing.